Got Milk?
The Effect of Export Price Shocks on Exchange Rates

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Abstract
I examine the effect of exogenous terms of trade shocks on an exchange rate by turning to New Zealand’s dairy auctions. Dairy is New Zealand’s largest export category, making up almost 20% of exports. Specifically, whole milk powder accounts for between 6 and 11% of total exports, and its price is determined in twice-monthly auctions. I use event studies to quantify the impact of surprise auction results on the New Zealand Dollar on a high-frequency basis. I find that a 1% increase in whole milk powder prices has a modest, but nevertheless significant, effect on the nominal exchange rate that does not seem to be explained by interest rate movements. Rather, the effect seems to be driven by a combination of two channels: a financial flows channel and an expenditure switching facilitation channel. I model this last channel by incorporating a non-traded sector into a small open-economy New Keynesian model, and I illustrate how nominal exchange rate changes can persist following a temporary export price shock, depending on the monetary policy rule. The methodology developed here can potentially be applied to other commodity exporters.

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1 Introduction

This paper provides novel evidence on the effect of terms of trade shocks on exchange rates using a high-frequency identification strategy. Theoretically, the nominal exchange rate should serve as an adjustment vehicle, facilitating expenditure switching as other prices in the economy change in response to shocks. The nominal exchange rate can also move if a shock induces a currency flow or if the central bank adjusts its policy rate in response to a shock. However, while standard theory suggests a causal response of nominal exchange rates to terms of trade shocks, the actual effect has remained difficult to both identify and quantify empirically.

More generally, although the exchange rate is arguably the most important price in a small open economy, as it is crucial in determining the economy’s standard of living, economists have struggled for decades to systematically find a connection between exchange rates and economic fundamentals. This exchange rate disconnect is classically documented in Meese and Rogoff (1983) and leaves policymakers and researchers without validated models to guide them. Part of the difficulty in identifying causal effects is that it is hard to find a shock to an exchange rate that is truly exogenous: most shocks impact the exchange rate through multiple channels or are already priced into the exchange rate.

I identify a setting that allows me to test the causal impact of an export price shock on an exchange rate: New Zealand dairy auctions, specifically the auction of whole milk powder (WMP). This setting is special for three reasons. First, it involves a single product that comprises a large portion of the export price index. Dairy is New Zealand’s primary export category, making up almost 20% of New Zealand’s exports, and WMP makes up between 6 and 11% of total exports.\textsuperscript{2} Thus, New Zealand’s export price index is highly correlated with the prices of dairy and whole milk powder (Figure 1). When dairy prices rise in New Zealand Dollar terms, this should feed through to the export price index and the exchange rate.

\textsuperscript{2}More specifically, it made up between 6 and 11\% of total exports between 2010 and 2019.
rate with a magnitude large enough to detect.

Figure 1: New Zealand export price indices

![Chart showing export price indices](image)

*Note:* The correlation between the whole milk powder price index and the overall export index is 0.77.

Second, WMP prices are announced at very precise times, and I can calculate surprise shocks in WMP prices at these times. Specifically, prices of various dairy products, including WMP, are determined at twice-monthly auctions. According to the Efficient Market Hypothesis, changes in WMP prices should not impact the New Zealand Dollar if these changes are expected and thus already priced into the New Zealand Dollar. I thus focus on the extent to which auction prices differ from expectations. Since WMP futures cash-settle to the auction-determined price, the expected auction price can be calculated from the futures price right before the auction with very few assumptions. The difference between actual and expected prices can be substantial, with auction prices ranging from 19% below to 33% above the expected auction price.

Third, surprises at these auctions are due to factors exogenous to the New Zealand economy. Supply is announced a few days in advance, so surprises are determined by foreign demand. Furthermore, I show that these demand shocks are dairy-specific and not indicative of changes to foreign income. These demand shocks arise at the auction because a subset of buyers is excluded from the futures market. While there are multiple countries where a single commodity makes up a large percentage of their export basket (e.g. copper in Chile.
or soy in Brazil), these second two ingredients are what make the New Zealand case unique. Results from this natural experiment may then inform our understanding of currencies from commodity-exporting countries in general.

Having identified an exogenous shock of sufficient magnitude, I calculate the response of the New Zealand Dollar to this shock at a high-frequency setting. This allows me to isolate the effect of the price shock on the exchange rate, since noise is limited in such a short window. Within the 15 minutes after WMP price shocks, the exchange rate appreciates about 0.01% for a 1% surprise increase in WMP prices.

This appreciation is statistically significant, and my study is the first to show a well-identified causal impact of terms of trade shocks on the exchange rate. However, the magnitude of this effect is lower than theory would suggest. Specifically, I would expect the nominal exchange rate to initially appreciate one-for-one with terms of trade increases. This prediction comes from a small open-economy model in the style of Galí and Monacelli (2005), in which the nominal exchange rate acts as an adjustment vehicle for expenditure switching. Because WMP makes up between 6 and 11% of total exports over the course of my study, I would expect the exchange rate to appreciate 0.06 to 0.11% for a 1% surprise increase in WMP prices.

There are two mechanisms through which terms of trade shocks can affect the nominal exchange rate, in addition to the expenditure switching mechanism. First, the monetary authority may change its policy rate in response to the impact of export prices shocks on aggregate demand. The nominal exchange rate would then adjust via the Uncovered Interest Parity (UIP). Second, if the terms of trade shock impacts demand for the New Zealand Dollar, and if financiers are constrained in their ability to meet this demand, then the nominal exchange rate will also adjust. These two mechanisms are only relevant in certain contexts: not all export price shocks induce a financial flow, and not all monetary policy rules would mandate a policy rate change in response to an export price change. I provide evidence that changing expectations around monetary policy do not seem to be
driving the nominal exchange rate response in my context, though the increase in financial flows likely contributes to the nominal exchange rate movement. However, back-of-the-envelope calculations illustrate that the financial flows mechanism is not likely to be the entire driving force. Rather, the nominal exchange rate movement seems to be driven by a combination of the financial flows and expenditure switching mechanisms. I model the expenditure switching mechanism by adding a non-traded sector to the Galí and Monacelli (2005) model. Impulse responses using the model show how the nominal exchange rate may remain persistently appreciated following a temporary foreign demand shock.

This paper fits into a few strands of the literature. First, it builds on the existing commodity currency literature (Gruen and Wilkinson, 1994; Amano and van Norden, 1995; Chen and Rogoff, 2003; Cashin, Céspedes and Sahay, 2004; Clements and Fry, 2008; Tokarick, 2008; Chen, Rogoff and Rossi, 2010; Powers, 2015). The empirical part of this literature uses time series methods to relate the terms of trade of a commodity-exporting country to its real exchange rate. For example, Chen and Rogoff (2003) look at how Australian, Canadian, and New Zealand real exchanges rates vary with real non-energy commodity prices over a 25-year period, adjusting for various assumptions about the data-generating process. Similarly, Cashin, Céspedes and Sahay (2004) find evidence of a long-run relationship between the real exchange rate and real commodity prices for certain countries. In contrast, my paper seeks a sharper identification approach by examining the exchange rate around exogenous shocks to the export price index. Additionally, results from the existing literature have found conflicting results around whether commodity price changes induce exchange rate movements. Because my paper relies on a stronger identification strategy than previously used, my findings show that export price shocks do indeed cause exchange rate movements.

Second, as mentioned earlier, my paper fits into the much larger exchange rate forecasting literature (Meese and Rogoff, 1983; Engel, Mark and West, 2007; Cheung, Chinn and Pascual, 2005; Gourinchas and Rey, 2007; Rossi, 2013). In general, this literature finds conflicting evidence on whether any of the standard theoretical exchange rate models translate
into empirical exchange rate prediction.

Finally, my methods stem from the high-frequency identification literature. A large literature examines the high-frequency impact of monetary policy shocks (Kuttner, 2001; Gürkaynak, Sack and Swanson, 2005; Hamilton, 2008; Campbell et al., 2012; Nakamura and Steinsson, 2018), while a smaller literature focuses on the high-frequency impact of exchange rate shocks (Andersen et al., 2003; Zettelmeyer, 2004; Faust et al., 2007). Unlike my paper, these papers have not looked into terms of trade shocks; instead, they focus either on announcements such as GDP and CPI or on monetary policy announcements.

The rest of the paper is organized as follows. Section 2 describes the dairy auctions and how they are relevant for the New Zealand economy. Section 3 describes my empirical approach in measuring the elasticity of the exchange rate to the terms of trade and provides evidence for critical identification assumptions. Section 4 presents the results of this elasticity identification. Section 5 discusses the three possible mechanisms through which terms of trade shocks might impact the nominal exchange rate and provides evidence that the exchange rate response is likely driven by a combination of induced financial flows and the nominal exchange rate’s more fundamental role as an expenditure switching vehicle for the economy. Section 6 presents the model, which illustrates the expenditure switching effect in a small-open economy context. Finally, Section 7 concludes.

2 Setting and the Relevance of GDT Auctions

In order to understand how terms of trade shocks affect an exchange rate, I zoom in on a particular setting: the New Zealand Dollar and Global Dairy Trade (GDT) auctions. These auctions involve eight different dairy items: whole milk powder (WMP), skim milk powder (SMP), butter, anhydrous milk fat (AMF), butter milk powder, cheddar, lactose, and sweet
whey powder.\textsuperscript{3} As discussed, dairy is New Zealand’s largest export good category.\textsuperscript{4} In fact three of the four largest dairy items traded in the GDT auction accounted for 10 to 16% of New Zealand’s goods and services exports between 2010 and 2018 (Figure 2), with whole milk powder alone accounting for 6 to 11%.\textsuperscript{5} This makes whole milk powder New Zealand’s single largest export, outside of the services sector, which is why I focus on WMP throughout this paper.\textsuperscript{6}

Figure 2: Top GDT products as a percent of exports over time

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\end{figure}

\textit{Note:} WMP, SMP, and butter are the first-, second-, and forth-largest items traded in the GDT auctions. AMF is the third-largest item, but export data for AMF is incorporated into a category with other goods. The export values of these products are shown as a percentage of total goods and services exports.

GDT auctions are held twice a month. They were first started in 2008 by Fonterra, New Zealand’s largest dairy producer, in order to give buyers and sellers more transparency in pricing and create recognized benchmark prices for their products. The auctions do indeed

\textsuperscript{3}Each item trades for multiple contract periods, which refers to the month in which the good will ship. For example, contract period 2 means that the product is shipped two months after the auction. The CP2 good traded in a May auction, for example, ships in July. The contract period definitions changed before the second auction in September 2011. Prior to this time, CP1 referred to the contract that shipped in the second month after the event.

\textsuperscript{4}From 2010 to 2014, it was the largest export category, including services. From 2015 to 2019, it was only surpassed by travel and tourism.

\textsuperscript{5}The four largest dairy items are WMP, SMP, butter, and AMF. I only have export data for WMP, SMP, and butter, since AMF is combined into a category with other goods.

\textsuperscript{6}Specifically, I focus on the contract specification CP2 for regular WMP sourced in New Zealand. I also include SMP in robustness checks in Appendix B. I do not consider butter or AMF, the other two products with NZX futures, due to the low traded volume of the futures and the added complication that the same product can be sold in either format, making supply forecasts in each product unstable.
serve their intended purpose of providing reference prices. As Figure 3 shows, the price of WMP sold in the GDT auction is highly predictive of the WMP export price index published by New Zealand’s official data agency. The lag appears because shipments occur after the auction date, and much of the visual difference in the two series is due to the fact that the WMP export price index is released quarterly, while the auction price is updated twice a month. In fact, from Q4 2010 to Q4 2019 the two series are 88% correlated, adjusting for shipping lags. This demonstrates the relevance of the GDT auction prices for New Zealand’s export price index. Furthermore, the price that Fonterra pays to its farmers, the Farmgate Milk Price, is calculated using primarily GDT prices for the WMP, SMP, and AMF price inputs, again providing evidence for the relevance of GDT prices.

Figure 3: Whole milk powder: auction price vs. export price index

As a final point, WMP auction prices exhibit a high degree of auto-correlation between auctions (Figure 4). This is important, because it means that auction prices reveal information about the future path of prices.

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7 Specifically, this figure shows the price of the largest contract specification sold in the GDT auctions (CP2, regular, produced in New Zealand).

8 Other discrepancies between the two series arise because only 18-32% of Fonterra’s WMP powder is actually sold in GDT auctions during this period. However, anecdotally, much of the off-auction sales happen in the twenty-four hours after the auction at the auction price, as shown by the high correlation between the export price index and the auction prices.

9 Between 2012 and 2016, GDT was the only price source for WMP, SMP, and AMF in the Farmgate Milk Price calculation. Since 2017, certain off-GDT sales were included; however, Fonterra notes in their 2019 Farmgate Milk Price Statement that including off-GDT sales only increased the Farmgate Milk Price by 1.6% relative to not including these off-GDT sales.
For all of these reasons, GDT auctions are watched by market participants as an indicator of export prices. This is exemplified by the following Wall Street Journal article on June 15, 2015, titled “New Zealand Dollar Down Late Eyes on Dairy Auction:”

*ASB Head of FX Institutional Sales Tim Kelleher said it was likely the New Zealand dollar would remain under pressure ahead of the Global Dairy Trade auction later in the week as markets wait to see whether there will be further falls in New Zealand’s largest export.*

This is made even more explicit in the following Wall Street Journal article from November 4, 2014:

*The Global Dairy Trade auction is closely watched as the GDT Price Index is widely considered a market reference price for dairy products.*

### 3 Empirical Approach for Elasticity Identification

Conceptually, the nominal exchange rate should respond to export price shocks in order to facilitate expenditure switching between foreign import goods and domestically-produced goods, the prices of which should increase either due to the income windfall for the country or due to mobile labor. The nominal exchange rate may also respond to export price shocks
if the shock induces a change in demand for the currency or if it prompts a change to the policy rate.

In order to estimate the extent to which WMP price movements impact the nominal exchange rate, I consider a regression of the form

\[ \Delta e_a = \alpha + \beta \Delta p_{aWMP} + \varepsilon_a \]  

where \( e \) is the log nominal exchange rate denominated in local currency per one unit of foreign currency and \( p_{WMP} \) is the log price of whole milk powder in US Dollars.\(^{10}\) Since export price increases should cause local currency appreciations (and since a positive movement in \( e \) indicates a local currency depreciation), we should expect \( \beta \) to be negative. In order to precisely identify the coefficient, I calculate \( \Delta e_a \) using minute-by-minute data in a tight window around GDT announcements. Results of the GDT auctions are not made public until the end of the auction when prices are published on the GDT website.\(^{11}\) Thus, prices are revealed at a very specific point in time, and exchange rates should react accordingly at that time. I identify the time of price announcements by recording the first Bloomberg headline containing the auction results.\(^{12}\) These Bloomberg headlines alert foreign exchange market participants as soon as GDT publishes the prices.\(^{13}\) Minute-by-minute exchange rate data comes from histdata.com.

My event window includes the 5 minutes prior to the announcement time through the 15 minutes after the announcement, in keeping with the literature (for example, Faust et al., 2007). Using such a short window allows me to isolate the impact of price announcements on the exchange rate by reducing outside noise. I assume that all other variables are fixed

\(^{10}\)Although \( p_{WMP} \) should ideally be in local currency, WMP is actually sold in US Dollars, so I will consider percent changes in US Dollar terms. However, when I convert \( \beta \) to reflect price changes in New Zealand Dollar terms, the coefficient will be quite similar.

\(^{11}\)Starting with the February 16, 2016 auction, GDT sold real-time access to their auctions via their “Insights” package. I exclude auctions after this date in Appendix B.

\(^{12}\)There are five days where the headline does not appear to be available on Bloomberg: February 18, 2014; March 4, 2014; April 1, 2014; January 2, 2019; March 5, 2019. I exclude these days from my high-frequency analysis.

\(^{13}\)Starting with the September 16, 2014 auction, Bloomberg automated this headline release.
during this window. I calculate the cumulative abnormal exchange rate return by comparing the cumulative returns during the event window to the average returns during my estimation window, the 60 minutes to 5 minutes before the announcement. I then compare this exchange rate response to the terms of trade shock. I specifically examine the NZD/AUD and NZD/USD exchange rates, since the US and Australia are the two countries with floating currencies that import the most dairy from New Zealand (Figure 5). Although China imports 18% of dairy and 32% of WMP from New Zealand, I don’t consider the Chinese Renminbi, because I don’t have high-frequency data on its exchange rate.

Figure 5: Top importers of New Zealand dairy

In trying to understand the true impact of terms of trade shocks, it is essential to break out the surprise, or unanticipated, component from the anticipated component of GDT price announcements. Exchange rates are forward looking and any expected news about economic fundamentals should be incorporated into the price in advance. WMP price announcements should only cause the exchange rate to vary if the announced price differs from the expected price. Thus, the relevant regression to identify $\beta$ is:

$$\Delta e_a = \alpha + \beta s_a + \varepsilon_a$$  \hspace{1cm} (2)$$

where $s$ denotes the surprise component of the announcement. In order to quantify the
response, it is critical to be able to calculated the expected WMP price and how the actual WMP price differs from expected.

Fortunately, this setting provides a simple way to calculate market expectations of the WMP auction price: WMP futures. Monthly WMP futures contracts have been traded on New Zealand’s Exchange (NZX) since October 2010 and settle at a price determined by the GDT auction prices. Specifically, a month’s WMP futures contract settles to the average contract-period 2 (CP2) price from the two GDT auctions that month. The contract is cash-settled the day after the second auction. Thus, the futures price right before an auction can be used to calculate market expectations of the WMP CP2 price in that auction. If I assume futures market participants are risk-neutral and have rational expectations, then the expected auction prices in auction \( n \in \{1, 2\} \) of month \( m \), which is on day \( t \) is given by:

\[
E_{t-1}(P_{WMP}^{n=1,m}) = F_{WMP,t-1}^m
\]

\[
E_{t-1}(P_{WMP}^{n=2,m}) = 2 \times F_{WMP,t-1}^m - P_{WMP}^{n=1,m}
\]

where \( P_{WMP} \) denotes the WMP auction price and \( F_{WMP,t-1}^m \) denotes the last WMP futures price of the day before the auction. The asymmetry between expectations ahead of the two auctions each month arises because the futures contract settles to the average of these two auction prices. I assume that ahead of the first auction, participants expect the same price for the two auctions that month. Ahead of the second auction, the other relevant price has already been determined, so the calculation does not require any assumptions. Daily WMP futures prices were provided by NZX, and historical auction prices and quantities were provided by GDT.

Because GDT auctions happen at noon GMT, which is overnight New Zealand time, there is an 8-9 hour gap between the closing time of the WMP futures market and the start of the auction. The expectation calculation relies on the assumption that there is no new

\[14\] In keeping with the contract period definition change in September 2011, up through the September 6, 2011 auction the futures settled to the CP1 price.
Given the expected WMP price, I can back out the surprise component of the WMP auction price for an auction \( a \):\(^{15}\)

\[
s_a = \ln(P_a^{WMP}) - \ln(E_{t-1}(P_a^{WMP}))
\]  

Specifically, \( s \) measures the percent deviation of the ultimate auction price from the expected auction price. Summary statistics from October 2010, when WMP futures were launched, through the end of 2019 are given in Table 1. A few notable features stand out. First, the mean of the surprise metric is very close to 0 (though a 95% confidence interval around the mean does not include 0). Second, the surprises can be quite large, up to 33% more than the expected price and as low as 19% less than the expected price.\(^{16}\)

\(^{15}\)There are four days where GDT did not publish WMP prices: July 15, 2015; August 4, 2015; November 3, 2015; March 7, 2017. I exclude these days from my analysis, as I cannot calculate the surprise metric. Prices were not published because bidding during the auction was insufficient to cause the announced price to rise above the starting price. For the second auction in August 2015, November 2015, and March 2017, I calculate the expected auction price as

\[
E_{t-1}(P_{WMP}^{n=2,m}) = F_{WMP,t-1}^m
\]

\(^{16}\)Figure 16 in Appendix A shows a graph of the surprise metric over time and Figure 17 shows its distribution.
Table 1: Summary statistics for the surprise metric

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>217</td>
</tr>
<tr>
<td>Mean</td>
<td>-0.010</td>
</tr>
<tr>
<td>95% CI of mean</td>
<td>[-0.018, -0.002]</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>0.057</td>
</tr>
<tr>
<td>Min</td>
<td>-0.192</td>
</tr>
<tr>
<td>Max</td>
<td>0.330</td>
</tr>
<tr>
<td>Mean of absolute value</td>
<td>0.041</td>
</tr>
</tbody>
</table>

This empirical set-up allows me to calculate the exchange rate response to the unanticipated component of a terms of trade shock; however, it is essential to show that the exclusion restriction holds, i.e. that auction surprises only affect the New Zealand Dollar through the WMP price. If surprises came from supply shocks, these surprises could reveal information about the broader New Zealand economy, violating the exclusion restriction. More specifically, economy-wide production shocks (such as weather events) might impact the prices of other goods in New Zealand’s consumption basket in ways other than through the price of WMP. Thus, the impact on the exchange rate would not solely be due to price changes in WMP, and I would misidentify $\beta$.

Fortunately for the experiment, supply is essentially fixed a few days in advance of the auction. Fonterra is the primary seller at the GDT auctions, supplying 99-100% of whole milk powder, and they publish auction supply forecasts three trading days before the auction. As Figure 7 shows, auction supply rarely deviates from the published forecasted amount. In fact, the mean squared error of using these forecasts to predict supply is only 469 MT, which is just 3% of the average quantity sold (18,076 MT). Thus, any auction surprises must come from buyer demand.\textsuperscript{17}

Therefore, the exclusion restriction holds as long as auction demand only affects the New Zealand economy (in particular, the price of the consumption basket) through auction sur-

\textsuperscript{17}It is possible that there could be supply shocks to non-GDT supply, which could impact buyer demand at the GDT auctions. For this not to be an issue, I need the added assumption that Fonterra sells a constant proportion of their total supply at GDT auctions. While the amount that Fonterra sells at GDT auctions ranges from 18 to 32% annually over the course of my study, this proportion is autocorrelated on a quarterly basis. The autocorrelation coefficient is 0.56, which is significant at the 0.001% level.
Figure 7: Fonterra’s final supply forecast for the upcoming auction

Note: Quantities refer to the sum across all contract periods. The red line is the 45-degree line. The first auction date graphed is October 18, 2011, due to data availability of Fonterra forecasts.

prises. Fortunately, demand on the GDT auctions comes almost entirely (if not entirely) from foreign participants. While GDT does not release data on the percentage of demand from outside New Zealand, less than 5% of WMP produced by Fonterra is consumed domestically,\(^\text{18}\) so it should follow that a similarly small amount of the product sold in GDT auctions is sold to domestic buyers.\(^\text{19}\) While the amount demanded by each country is not public, North Asia, which includes China, accounts for the majority of demand (Figure 8). It receives 55% of all WMP auction supply on average over the course of my sample, though this amount is highly variable, ranging from 12% to 91% with an overall standard deviation of 15.7% (Table 2).\(^\text{20}\)

Furthermore, there is segmentation of participants between the auction and the futures markets, with auction buyers more demand-informative than futures market participants. Capital controls in China, as well as other countries in Southeast Asia, prevent auction buyers in these countries from engaging in the futures market unless they have offshore offices. Additionally, NZX derivatives brokers only serve clients of a certain size, and none of the 50 official global Fonterra resellers who buy on the GDT platform are large enough to

\(^{18}\)Fonterra statement, August 1, 2011.
\(^{19}\)Anecdotally, the percent sold domestically at GDT auctions is quite a bit smaller.
\(^{20}\)Anecdotally, “demand is driven by a small number of Chinese buyers.”
work with these brokers. Thus, demand shocks from these participants will be revealed at auction.

Although demand comes from primarily foreign buyers, and although these buyers are more demand-informative than futures market participants, we might worry about two potential issues that would violate the exclusion restriction: (1) demand could be reflecting expectations of future New Zealand supply, which is reflective of New Zealand economic conditions, and (2) demand might reveal information about Chinese growth, which could impact New Zealand exports through channels other than the milk price. The first worry is mitigated by the fact that it is unlikely that foreign buyers have private information about

Table 2: Summary statistics for amount sold to each region

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean (MT)</th>
<th>Std. dev. (MT)</th>
<th>Mean (%)</th>
<th>Std. dev. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>1090</td>
<td>1001</td>
<td>6.1</td>
<td>5.9</td>
</tr>
<tr>
<td>EU</td>
<td>147</td>
<td>257</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Middle East</td>
<td>1923</td>
<td>1323</td>
<td>11.0</td>
<td>6.5</td>
</tr>
<tr>
<td>North America</td>
<td>12</td>
<td>55</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>North Asia</td>
<td>10,221</td>
<td>5976</td>
<td>55.1</td>
<td>15.7</td>
</tr>
<tr>
<td>South and Central America</td>
<td>516</td>
<td>689</td>
<td>2.9</td>
<td>3.8</td>
</tr>
<tr>
<td>South East Asia and Oceania</td>
<td>3994</td>
<td>2088</td>
<td>24.0</td>
<td>11.0</td>
</tr>
</tbody>
</table>

This table gives amount sold, in MT and percentile terms, to each region from October 2010 until December 2019.
future New Zealand supply, especially since futures market participants include New Zealand dairy suppliers. WMP futures market participants include the entire WMP supply chain, including companies with contracts that link prices to the GDT auctions but who have not been approved to participate in GDT auctions.\footnote{NZX has a separate futures product geared towards farmers, which settles to a New Zealand Dollar price that references the Farmgate Milk Price, which is the price Fonterra pays its farmers. For this reason, farmers tend not to participate in the WMP futures market.} This includes certain non-Fonterra dairy blenders and processors in New Zealand who sell abroad. It seems unlikely that a foreign GDT buyer would know more about future New Zealand supply than these companies. While their auction demand may reflect expectations about future WMP supply from locations other than New Zealand, this does not violate the exclusion restriction.

Additionally, Fonterra forecasts supply for an additional four auctions when they forecast supply for the upcoming auction. Thus, all market participants know Fonterra’s forecast for the next two months of auctions a few days before each auction, and futures markets should take this information into account. Figure 9 shows that Fonterra’s 2-month ahead forecasts are not as reliable predictors of actual auction supply,\footnote{The mean squared error of using these forecasts to predict supply is 4121 MT, almost nine times the MSE of the final forecast.} but it seems fair to say buyers and futures markets will have the same information about supply up to 5 auctions ahead.

Figure 9: Fonterra’s supply forecast for the auction four auctions after the upcoming one

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure9.png}
\caption{Fonterra’s supply forecast for the auction four auctions after the upcoming one}
\end{figure}

\textit{Note:} Quantities refer to the sum across all contract periods. The red line is the 45-degree line.
The second worry is somewhat mitigated by the fact that dairy is a small portion of the Chinese economy. Dairy was only 0.3% of total Chinese imports in 2018 and only 0.4% of Chinese GDP in 2017. However, this does not assuage the worry; one could imagine a story where a higher degree of demand from China for whole milk powder indicates that Chinese families are wealthier and therefore are demanding more foreign infant formula, for example. Wealthier Chinese families would have other knock-on effects on non-WMP New Zealand exports, as well as the exports of other economies that are closely tied to China’s. As a result, \( \hat{\beta} \) would overestimate the magnitude of the true effect of WMP price shocks on the exchange rate. I provide evidence that this is not the case by running placebo tests, in which I replace the New Zealand exchange rate in Equation 2 with other exchange rates: the Australian Dollar, the Hong Kong Dollar, the Japanese Yen, and the Singapore Dollar, all measured against the US Dollar. I run additional placebo tests in which I replace the New Zealand exchange rate with commodity prices, specifically gold, silver, and WTI crude oil. If auction prices revealed news about Chinese demand that would affect the New Zealand Dollar through pathways aside from export prices, we would expect these changes to be reflected in other countries’ currencies as well. However, as Table 3 shows, I find that this is not the case: none of these other currencies or commodities react to milk price shocks, providing evidence for the exclusion restriction.\(^{23}\)

As I have demonstrated, the fact that auction supply is known before the futures close ahead of the auction is critical for the exclusion restriction to hold. In other words, supply is constant in the determination of both \( P_a^{WMP} \) and \( E_{t-1}(P_a^{WMP}) \), so \( \hat{\beta} \) will not reflect production shocks, and the elasticity estimate will be unbiased. The WMP market is unique in that I have \( P_{t=1} \) and \( E_{t=0}(P_{t=1}) \), since the GDT auction price represents the spot price of the commodity, and since WMP futures cash-settle to the GDT price. In most commodity markets, futures settle to the volume-weighted average of trades in the settlement period.

\(^{23}\)Even if WMP price surprises did reveal information about Chinese growth, a weaker exclusion restriction that auction surprises only affect the New Zealand Dollar through the export price index would still hold. I would still be able to show whether terms of trade shocks impact the New Zealand Dollar; however, I would be less able to assess the magnitude of the response.
Table 3: The impact of surprise WMP changes on various currencies and commodities within 15 minutes after the announcement

<table>
<thead>
<tr>
<th></th>
<th>(1) USD/AUD</th>
<th>(2) HKD/USD</th>
<th>(3) JPY/USD</th>
<th>(4) SGD/USD</th>
<th>(5) WTI</th>
<th>(6) Silver</th>
<th>(7) Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise ∆ WMP</td>
<td>0.0003</td>
<td>−0.0000</td>
<td>−0.0008</td>
<td>0.0004</td>
<td>0.0015</td>
<td>−0.0012</td>
<td>0.0011</td>
</tr>
<tr>
<td></td>
<td>(0.0015)</td>
<td>(0.0001)</td>
<td>(0.0012)</td>
<td>(0.0007)</td>
<td>(0.0055)</td>
<td>(0.0042)</td>
<td>(0.0025)</td>
</tr>
<tr>
<td>Constant</td>
<td>−0.0000</td>
<td>0.0000</td>
<td>−0.0000</td>
<td>0.0001*</td>
<td>−0.0005</td>
<td>−0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>(0.0001)</td>
<td>(0.0000)</td>
<td>(0.0001)</td>
<td>(0.0000)</td>
<td>(0.0003)</td>
<td>(0.0002)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
<td>212</td>
<td>212</td>
<td>212</td>
<td>212</td>
<td>212</td>
<td>212</td>
</tr>
<tr>
<td>R2</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
</tbody>
</table>

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Coefficients displayed with standard errors in parentheses.
(often the last minute of the trading day). Additionally, spot prices are not continuously traded on a transparent market with known reference prices, so we do not know \( P_{t=1} \). Thus, in most commodity markets we would have to proxy the surprise metric with

\[
\ln \mathbb{E}_{t=1}(P_{t=2}) - \ln \mathbb{E}_{t=0}(P_{t=1})
\]

Of course, if one were to choose a time frequency such that \( t = 0 \) and \( t = 1 \) were sufficiently close together, and if one were to identify a demand shock within that time period, one could assume that supply does not change. This is the theory behind high-frequency event studies. The problem, however, is that it is hard to identify commodity-specific shocks to demand that can be isolated to a specific minute or hour, or some time short enough for the assumption of constant supply to be valid. Demand shocks that come from shocks to foreign countries’ incomes would violate the exclusion restriction; shocks need to come from foreign taste shocks or other idiosyncratic commodity-specific shocks. Furthermore, the demand shock would have to surprise all futures market participants, either due to the nature of the shock or market segmentation. Overall, it is difficult to find a large enough sample of such shocks to identify the exchange rate elasticity. This is why the New Zealand case is special; it is a uniquely well-identified experiment, results from which may be applied to other commodity-producing countries.

4 Results of Elasticity Identification

In order to assess the effect of WMP price shocks on the New Zealand exchange rate, I start by splitting auction dates into terciles depending on the surprise metric and examining whether the exchange rate responds differently on the three categories of days. Figure 10 shows that on auction days with negative WMP price surprises, the New Zealand Dollar tends to depreciate immediately following the announcement, while on auction days with positive WMP price surprises, the New Zealand Dollar tends to immediately appreciate.
following the announcement. Figure 11 shows a specific example of the sudden reaction to the announcement. The announcement contains news that immediately moves the exchange rate in the direction we would anticipate.

Figure 10: Mean exchange rate changes by surprise group tercile

(a) USD/NZD

(b) AUD/NZD

Figure 11: Example of exchange rate response

Note: Line gives WMP price announcement time. The WMP price was 10% less than expected.

I report my results for my baseline specification (Equation 2) in Table 4. Columns 1 and 3 show that the New Zealand Dollar appreciates 0.010% and 0.009% against the US Dollar and the Australian Dollar respectively for a 1% increase in the surprise component
This effect is significant at the 1% level. Exchange rates do respond to terms of trade shocks. Namely, when the export price index suddenly and unexpectedly increases, the exchange rate appreciates. Figure 12 shows these results graphically in scatter plots in order to demonstrate results are not driven by a single outlier event.

Table 4: The impact of surprise WMP changes on the New Zealand Dollar within 15 minutes after the announcement

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NZD/USD</td>
<td>NZD/USD</td>
<td>NZD/AUD</td>
<td>NZD/AUD</td>
</tr>
<tr>
<td>Surprise ∆ WMP</td>
<td>–0.010***</td>
<td>–0.012***</td>
<td>–0.009***</td>
<td>–0.011***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Expected ∆ WMP</td>
<td>–0.004*</td>
<td></td>
<td>–0.005***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
<td>209</td>
<td>212</td>
<td>209</td>
</tr>
<tr>
<td>R2</td>
<td>0.090</td>
<td>0.104</td>
<td>0.167</td>
<td>0.183</td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

Columns 2 and 4 in Table 4 show that controlling for the expected change in WMP auction prices increases the magnitude on the unanticipated component slightly, to 0.012% and 0.011% for the USD and AUD exchange rates respectively. This is because the expected change in price is negatively correlated with the surprise metric. Table 5 shows that when markets expect prices to rise by 1% since the last auction, prices tend to be 0.4% lower than expected. They still rise by 0.6% over the last auction, but they do not rise as much as expected.

24 Note that WMP auction prices are denominated in USD. In order to calculate the elasticity of exchange rates to WMP prices denominated in New Zealand Dollars, note

$$\Delta WMP^{NZD} = \Delta WMP^{USD} - \Delta e$$

For a 1% increase in USD WMP prices, the exchange rate appreciates 0.01% and NZD WMP prices increase by 1.01%. Thus, the exchange rate appreciates \( \frac{0.01}{1.01} = 0.0099\% \) for a 1% increase in NZD WMP prices.
Figure 12: Correlation between surprise WMP price changes and the NZD exchange rate

![Figure 12](image)

(a) USD/NZD  
(b) AUD/NZD

Table 5: Correlation between the expected and unanticipated components of WMP price changes

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surprise Δ WMP</td>
<td>Total Δ WMP</td>
</tr>
<tr>
<td>Expected Δ WMP</td>
<td>-0.409***</td>
<td>0.591***</td>
</tr>
<tr>
<td></td>
<td>(0.062)</td>
<td>(0.062)</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.005</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>Observations</td>
<td>209</td>
<td>209</td>
</tr>
<tr>
<td>R2</td>
<td>0.174</td>
<td>0.306</td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

It is somewhat surprising that the coefficient on the expected change in price in Columns (2) and (4) of Table 4 is significant. Although according to the Efficient Market Hypothesis, exchange rates should only react to unanticipated changes in price, they also seem to be reacting to the anticipated component of the change in price. Perhaps this reflects the fact that not all market participants are so rational as to be conditioning on the futures prices, so they interpret any change in WMP prices as news, whether it be expected or unexpected. That said, this coefficient is not significant in single-variate regressions, as shown in Table 6.

In order to understand the benefits of my tight event window and provide evidence for the
Table 6: The impact of expected WMP changes on the New Zealand Dollar within 15 minutes after the announcement

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative abnormal Δe</td>
<td>Cumulative abnormal Δe</td>
</tr>
<tr>
<td></td>
<td>NZD/USD</td>
<td>NZD/AUD</td>
</tr>
<tr>
<td>Expected Δ WMP</td>
<td>0.000</td>
<td>−0.000</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.000*</td>
<td>0.000*</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>209</td>
<td>209</td>
</tr>
<tr>
<td>R2</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

The usefulness of a high-frequency event study in this context, I run the specifications in Columns (1) and (3) from Table 4 with event windows that gradually lengthen by 15 minutes. Figure 13 shows how standard errors get increasingly larger after the shortest event window such that the response no longer seems significant. This points to the benefit of high-frequency identification with a short event window for studying exchange rate responses: exchange rates are subject to a lot of noise.

Figure 13: The effect of surprise increases in WMP prices on the NZD exchange rate with a lengthening event window

![Figure 13: The effect of surprise increases in WMP prices on the NZD exchange rate with a lengthening event window](image)

(a) USD/NZD

(b) AUD/NZD

Note: Bars denote 95% confidence intervals.
However, we can see that the point estimate drifts such that the magnitude rises with a longer event window. Although it is important to be careful in over-interpreting this due to the rising standard errors, this is a similar pattern to that seen in the post-earnings-announcement drift literature.\textsuperscript{25} Markets may take time to process the information from the auction, and the immediate response within the first fifteen minutes after the event may not be the entire response. This is especially likely when we consider that auctions take place overnight from a New Zealand perspective. This points to an efficiency-bias trade-off: a longer event window may give us a better sense of the actual magnitude of the exchange rate response, while a shorter window guarantees less noise and smaller standard errors.

Despite the fact that exchange rates are quite noisy, which points to the benefits of high-frequency event studies to identify and detect exchange rate responses, GDT auction days are correlated with higher realized volatility of the New Zealand Dollar. Specifically, the standard deviation of the minute-by-minute AUD/NZD exchange rate is 0.0007 higher on auction days than non-auction days, which corresponds to 65\% of the mean standard deviation. For the USD/NZD exchange rate, this number is 0.0009, which corresponds to 43\% of the mean standard deviation.

5 A Discussion of Mechanisms

In order to differentiate the specific mechanisms that might cause nominal exchange rates to react to export price shocks, I turn to the fundamental equation of the log nominal exchange rate (Campbell and Clarida, 1987; Froot and Ramadorai, 2005):

\begin{equation}
    e_t = -\sum_{j=0}^{\infty} \mathbb{E}_t(i_{t+j} - i^*_{t+j}) - \mathbb{E}_t \sum_{j=0}^{\infty} r x_{t+j} + \lim_{j \to \infty} \mathbb{E}_t e_{t+j+1}
\end{equation}

where $e$ is the log nominal exchange rate denominated in local currency per one unit of foreign currency, $i$ is the domestic risk-free interest rate, $i^*$ is the foreign risk-free interest rate, and

\textsuperscript{25}See Fink (2021) for a review.
\( rx \) is the log excess return of the exchange rate. This equation comes from iterating forward the standard Uncovered Interest Rate Parity (UIP) equation, with an extra deviation term added in:

\[
e_t = -(i_t - i_t^*) - \mathbb{E}_t rx_{t+1} + \mathbb{E}_t e_{t+1}
\]

As Equation 4 illustrates, there are three potential terms through which the terms of trade could affect the nominal exchange rate: (1) direct monetary policy, (2) UIP deviations, which may be induced by financial flows, or (3) changes in economic fundamentals that affect the nominal exchange rate. Specifically, this last term corresponds to the role the nominal exchange rate plays in expenditure-switching. I consider each potential explanation in turn. Ultimately, I find that the nominal exchange rate seems to be driven by a combination of the financial flows and fundamental channels. While monetary policy mediates the fundamental effect, I rule out a direct monetary policy channel where the nominal exchange rate moves because of the impact of dairy prices on aggregate demand. Importantly, as Section 6 illustrates, the fundamental channel is operative regardless of whether the terms of trade shock is persistent.

5.1 Direct Monetary Policy Channel

Under the monetary policy channel, my empirical results might simply reflect a monetary policy rule that is sensitive to terms of trade shocks and an exchange rate moving in line with expected interest rates according to UIP. Terms of trade shocks can theoretically affect the domestic policy rate through one of two offsetting channels. First, an increase in the price of the export good (here, milk) may increase the aggregate demand from farmers and related industries. In this sense, the milk price increase is similar to any other demand shock from the dairy industry. The monetary authority may respond to this increase in demand by raising interest rates. If the exchange rate is only responding via this channel, expected interest rate changes would be a sufficient statistic for the terms of trade shock and the
nominal exchange rate would be driven entirely by monetary policy. This pathway is what I mean by the “direct monetary policy channel.”

Second, an increase in the terms of trade may cause the exchange rate to appreciate for non-monetary policy reasons, either via the financial flow channel or the fundamental channel. This would cause foreign goods to become cheaper, which would decrease domestic CPI. If the monetary authority targets CPI, they would respond by decreasing the interest rate. In this sense, monetary policy is also an important factor in mediating the financial flow and fundamental channels.26,27

I first provide evidence against the direct monetary policy channel by showing that expected interest rate changes are not a sufficient statistic for terms of trade shocks. I do this by adding the interest rate spread as an explanatory variable in Equation 2:

$$\Delta e_a^{NZD/f} = \alpha + \beta s_a + \gamma \Delta i_{\tau,a}^{f-NZ} + \varepsilon_a$$

As before, $\Delta e_a$ gives the change in the log exchange rate around the WMP price announcement and $s_a$ quantifies the surprise component of the announcement. Additionally, $\Delta i_{\tau,a}^{f-NZ}$ gives the change in the interest rate spread around the announcement between New Zealand government bonds of tenor $\tau$ and foreign country $f$’s government bonds of tenor $\tau$. I consider the spread of the New Zealand 1-year interest rate to both the US 1-year interest rate and the Australian 1-year interest rate. Changes in these interest rates reflect market expectations

26The RBNZ does indeed consider all these different channels, as evidenced by conversations with RBNZ economists.

27There are multiple consequences of nominal exchange rate appreciations on the New Zealand economy. Exchange rate appreciations adversely affect exporting firms. Those who price their goods in New Zealand Dollars will see their goods become less competitive, while those who price their goods in foreign currency will make less profit in New Zealand Dollar terms. Similarly, import-competing firms will face more competition from cheaper foreign goods. New Zealand households, however, benefit from appreciated exchange rates and see higher real disposable incomes due to these cheaper foreign goods. A monetary authority that fights appreciated exchange rates may be seen as one that prioritizes exporting and import-competing firms. In contrast, a monetary authority that fights depreciated exchange rates may be seen as one that prioritizes households. The Reserve Bank of New Zealand does have an inflation target band, and the RBNZ governor can be fired in the event that actual inflation deviates from this target band. This might imply that the RBNZ is politically independent and prioritizes its inflation target over various domestic interest groups. However, the RBNZ is not considered one of the more independent central banks, since the government may override the agreement that fixes the target band (the Policy Target Agreement).
of interest rate changes over the next year. Because GDT auctions take place at noon GMT, which is overnight in New Zealand, and since New Zealand bonds are not liquid overnight, I consider daily exchange rate and interest rate returns for Equation 5.

Results are given in Tables 7 and 8. The USD daily result without the interest rate spread control is given in Column 1 of Table 7. The New Zealand Dollar appreciates 0.010% against the USD for a 1% surprise increase in WMP prices over the course of the day around the dairy auction. This is identical to the high-frequency estimate of 0.010%, though as we would expect from the increasing standard error bars in Figure 13, the daily result is not significant. Including the interest rate spread return (Column 3) does not cause this estimate to change. Indeed, there is not a significant response of the exchange rate to the interest rate. In Table 8, I use the Australian Dollar exchange rate and the interest rate spread to the Australian 1-year government bond. The NZD/AUD exchange rate is indeed sensitive to the interest rate spread, and the elasticity has a larger magnitude than the elasticity to WMP price shocks (though is still less than UIP would predict). However, including the interest rate spread in the regression does not change the elasticity to WMP price shocks, which is significant in Columns (1) and (3), providing evidence that this elasticity is not driven by changing expectations around monetary policy. There is another pathway at work.

Next, I investigate how monetary policy responds to terms of trade shocks. As discussed, the monetary authority may either raise or lower the interest rate in response to terms of trade shocks, depending on their policy rule and on the strength of the financial flows and fundamental channels. If the monetary authority raises the interest rate in response to increases in WMP prices, previous estimates in Section 4 would overestimate the long-run effect. If it lowers the interest rate in response to increases in WMP prices, these estimates would underestimate the long-run effect.

In order to try to distinguish between these two monetary policy response types, I replace
Table 7: The daily impact of surprise WMP changes on the NZD/USD exchange rate, controlling for interest rate spreads

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/USD</th>
<th>(2) NZD/USD</th>
<th>(3) NZD/USD</th>
<th>(4) NZD/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise Δ WMP</td>
<td>−0.010</td>
<td>−0.010</td>
<td>−0.021**</td>
<td>−0.021**</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>Δi_{1y}^{US−NZ}</td>
<td>−0.004</td>
<td>−0.005</td>
<td>−0.003</td>
<td>−0.025***</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.011)</td>
<td>(0.010)</td>
<td>(0.008)</td>
</tr>
<tr>
<td>Expected Δ WMP</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>217</td>
<td>212</td>
<td>212</td>
<td>211</td>
</tr>
<tr>
<td>R2</td>
<td>0.007</td>
<td>0.001</td>
<td>0.007</td>
<td>0.046</td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

the dependent variable in Equation 2 with the New Zealand interest rate:

$$Δi_{τ,a}^{NZ} = α + βs_a + ε_a$$

(6)

where $i_{τ,a}^{NZ}$ is the New Zealand interest rate on a government bond with tenor $τ$. Similar to my empirical approach for finding the elasticity of the exchange rate to the terms of trade, I again utilize the fact that interest rates should only respond to unanticipated changes in the price of WMP. A positive sign on the coefficient estimate would point to the first pathway above, where the increase in the price of WMP acts as a demand shock. A negative sign would point to the second pathway, where the monetary authority counteracts other exchange rate effects due to CPI targeting. Of course, the monetary authority does not respond within a day to WMP price changes; these interest rates measure how the market anticipates the RBNZ will respond. For example, changes to the 1-year interest rate measure how the market anticipates the RBNZ will respond within the year.

As Table 9 shows, New Zealand interest rates do not seem to move with surprise WMP
Table 8: The daily impact of surprise WMP changes on the NZD/AUD exchange rate, controlling for interest rate spreads

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/AUD</th>
<th>(2) NZD/AUD</th>
<th>(3) NZD/AUD</th>
<th>(4) NZD/AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise $\Delta$ WMP</td>
<td>$-0.011^{**}$</td>
<td>$-0.010^{*}$</td>
<td>$-0.013^{**}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.006)</td>
<td></td>
</tr>
<tr>
<td>$\Delta i_{AU-NZ}$</td>
<td>$0.054^{***}$</td>
<td>$0.052^{***}$</td>
<td>$0.053^{***}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.018)</td>
<td>(0.017)</td>
<td>(0.017)</td>
<td></td>
</tr>
<tr>
<td>Expected $\Delta$ WMP</td>
<td>$-0.006$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>$-0.000$</td>
<td>$-0.000$</td>
<td>$-0.000$</td>
<td>$-0.000$</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>217</td>
<td>212</td>
<td>212</td>
<td>211</td>
</tr>
<tr>
<td>R2</td>
<td>0.020</td>
<td>0.043</td>
<td>0.059</td>
<td>0.066</td>
</tr>
</tbody>
</table>

*p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

prices. From a Dornbusch (1976) perspective, this would be the optimal policy if the price shocks were permanent. However, as the model in Section 6 shows, this is potentially puzzling if we consider a temporary shock and a monetary authority that targets CPI inflation.28

28 This can be reconciled in the context of Dornbusch (1976), where the monetary authority might be acting to stop interest rate movements that would naturally arise from temporary price shocks. In a basic Keynesian model, GDP and interest rates are positively correlated. If GDP rises due to a WMP price increase, interest rates would naturally rise to bring money demand in line with unchanged money supply. In order for the UIP to hold, the nominal exchange rate would appreciate then depreciate, similar to the classic Dornbusch (1976) overshooting result. If the monetary authority values stability to the nominal exchange rate, perhaps due to CPI targeting, they may act to keep interest rates from rising. This corresponds to the second monetary policy pathway, in which the monetary authority lowers interest rates after WMP price increases, but it would appear in the data as an unchanged interest rate. It would also correspond to lower coefficient magnitudes in my baseline regression than if the shock were permanent and monetary policy were nonreactive.
Table 9: The daily impact of surprise WMP changes on New Zealand government bond yields of different tenors

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise ∆ WMP</td>
<td>0.005</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.013)</td>
<td>(0.016)</td>
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<tr>
<td>Constant</td>
<td>-0.000</td>
<td>-0.000</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
<td>212</td>
<td>212</td>
</tr>
<tr>
<td>R2</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* * p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

5.2 Financial Flows

From the perspective of a Gabaix and Maggiori (2015) type model, exchange rates might move with export prices because an increased export flow might increase the global demand for the New Zealand Dollar.²⁹ Financiers mediate this flow but have limited risk-bearing capacity, generating an appreciation of the New Zealand Dollar via the UIP deviation term in Equation 4.

To see how this story translates into my setting, I need to consider the financial flow that would happen after the GDT auction. Whole milk powder is denominated and traded in US Dollars, meaning that Fonterra is bearing the currency risk of the auction. When USD prices are higher than expected, Fonterra will be paid a higher amount of US Dollars which they will then need to exchange for New Zealand Dollars. If financiers need to mediate this exchange and if they are limited in their risk-bearing capacity, they would demand a currency risk premium for this trade, causing the New Zealand Dollar to appreciate. According to Fonterra’s financial statements, USD sales revenues are indeed fully converted into NZD.³⁰

²⁹There is a growing literature that considers how exchange rates might be determined by financial flows in imperfect financial markets (Gabaix and Maggiori, 2015; Greenwood et al., 2020; Gourinchas, Ray and Vayanos, 2020; Jiang, Krishnamurthy and Lustig, 2021; Itskhoki and Mukhin, 2021).

³⁰Fonterra enters into foreign currency forward and option contracts for forecasted cash receipts up to 18 months in the future. If total revenue, however, is different than expected when the hedge was entered into,
In this way, my setting is one of only a few documented in the literature where we know that currency is converted and that the financial flows story is relevant.\footnote{For others, see Hau, Massa and Peress (2010), Pandolfi and Williams (2019), and Broner et al. (2020).}

In Appendix C, I show a few tests of the financial flow mechanism. First, I test whether my baseline high-frequency estimates are driven by days when financiers are more likely to be constrained, based on their positions in the exchange-traded futures market. While this is a much smaller and less relevant market than the over-the-counter spot and forwards markets, it is the only market for which data is publicly available. Second, I test for high-frequency covered interest rate parity (CIP) deviation changes after WMP price announcements, which can arise in the case where financiers’ risk-bearing capacity is not a function of exchange rate volatility.\footnote{Specifically, CIP fails in the Gabalex and Maggiori (2015) model when their $\alpha = 0$. While UIP always fails in the model and I would ideally test whether UIP deviations arise in my setting, I cannot observe UIP deviations at such a high frequency.} Unfortunately both are weak tests in that significant results would provide evidence for the financial flows mechanisms, but the lack of significant results does not rule out the mechanism. Thus, the fact that neither test provides evidence for the mechanism is not necessarily informative. Given that there must be a financial flow due to unexpected Fonterra demand for currency, this mechanism is likely in effect.

In order to get a sense of whether the financial flow mechanism is driving the entire nominal exchange rate movement, I use a simple back-of-the-envelope calculation to estimate the elasticity of the nominal exchange rate to the surprise \textit{quantity} of financial flows, and I compare this elasticity estimate to the existing literature. In my high-frequency estimates, I find that a 1\% WMP price surprise corresponds to a 0.01\% nominal exchange rate appreciation. This 1\% WMP price surprise can be multiplied by the quantity of WMP exported per auction to calculate a financial flow size. However, given that a large portion of New Zealand WMP is not actually sold at GDT auctions but is benchmarked to GDT prices, it is hard to know the exact quantity exported. The actual revenue of WMP sold in the auction gives a lower bound for this estimate and averages 59 million USD. Total annual New Zealand WMP they will need to either buy or sell the New Zealand Dollar in order to fully convert their receipts.
exports divided by the number of auctions in a year gives an upper bound and averages 188 million USD. A fair middle ground would be to take this upper bound and multiply it by 0.88, which is the correlation between the WMP export price index and the auction price over the course of my sample. This averages 166 million USD. This would imply that a 1.66 million USD flow leads to a 1% nominal exchange rate movement. The average annual New Zealand GDP from 2010 to 2019 was 187,855 million. This means that a 1% surprise inflow as a percent of GDP leads to an 11% appreciation.\textsuperscript{33} In contrast, Broner et al. (2020) found that a 1% inflow as a percent of GDP led to an 0.9% appreciation in their setting. The fact that I get such a large elasticity given the relatively small size of the associated financial flows implies that while these financial flows are likely part of the story, the fundamental channel is also likely in effect.

\textbf{5.3 Fundamental Channel}

Finally, I turn to the last channel, which I call the fundamental channel. In this channel, the nominal exchange rate serves as an adjustment vehicle for the economy in response to an external shock. Specifically, an increase in the price of dairy causes an increase in prices across production sectors in the economy. Conceptually, this can arise either due to an increase in the income of the economy, which is spent across the entire basket of consumption goods, or mobile labor and wage equalization. In response to these higher prices, the nominal exchange rate appreciates, thus facilitating an expenditure switching effect towards foreign import goods. Additionally, the rise in prices in the consumption basket translates into a real exchange rate appreciation. I model this mechanism in Section 6.

Monetary policy can play an important role in this channel, even as it is distinct from the “direct” monetary policy channel. The ultimate impact of the external shock on the exchange rate depends on the monetary policy response to the shock, which depends on the shock’s permanence. According to Dornbusch (1976), if the shock is permanent, real exchange rate

\textsuperscript{33}With my lower bound of the financial flow size, this number rises to 32%. With my upper bound, the number falls to 10%.
The document discusses the implications of nominal exchange rate appreciations in the context of commodity prices. It notes that appreciations should be entirely absorbed by nominal exchange rate appreciations, without a change in the price level or the interest rate. As Figure 14 shows, however, WMP price shocks seem to be temporary, and prices mean-reverted over the course of roughly a year during this period. This mean-reversion is a documented feature of agriculture commodity prices (Peterson, Ma and Ritchey, 1992; Bessembinder et al., 1995; Wang and Tomek, 2007).

If the external shock is temporary and if the monetary authority targets CPI inflation, as it does in the case of New Zealand, then the monetary authority should lower the interest rate in response to the CPI inflation reduction induced by the nominal exchange rate appreciation. This is illustrated in my model, but it makes the lack of interest rate response to WMP price surprises somewhat puzzling. That said, the model also illustrates a case where the exchange rate response is due to structural changes in the market.

---

34 This result is explained in Obstfeld and Rogoff (1996). It relies on a few assumptions, namely that UIP holds, real money balances are proportional to interest rates and output, prices and output are sticky in the short-run, and money is neutral in the long run.

35 This does not rule out the possibility of a persistent component to WMP prices. Both cyclical and structural elements drove WMP price movements during my sample period. The cyclical factors had to do with supply: a 2013 drought and the strong supply response. The structural factors had to do with Chinese growth and as well as a changing milk market in China as part of their government’s efforts to improve milk quality. Because my event study setting controls for supply, price shocks reflect shocks to demand, which are more likely to be indicative of structural changes to the WMP market.

36 In standard commodity models, prices of storable commodities follow a random walk (Deaton and Laroque, 1992). That said, WMP is not infinitely storable, and recommended storage is 24 months. The documented mean-reversion in agriculture markets may be explained by a supply response to price movements.
rate responds to a temporary external shock without an associated interest rate response: the case where the monetary authority targets export price inflation and is able to avoid any deviations from this target. However, this case may be less applicable to a more complex world.

As my estimated coefficient of the elasticity of nominal exchange rate movements to WMP price surprises is larger than can be explained by the financial flows channel, this fundamental channel is likely in effect. In order to better illustrate this channel, as well as to derive the elasticity coefficient that would arise from this channel, I turn to the model in Section 6.

6 Model of the Nominal Exchange Rate

This section models the impact of temporary foreign demand shocks on the nominal exchange rate in a small country setting. In doing so, it illustrates how nominal exchange rate movements can persist beyond a temporary foreign demand shock for the export good.

Specifically, the model adds a non-traded sector into the small open economy New Keynesian model of Galí and Monacelli (2005). Models that use a traded and non-traded sector are widely used in the open economy literature (e.g. Obstfeld and Rogoff, 1996; Frankel, 2010; Uribe and Schmitt-Grohé, 2017) and allow adjustment to take place through the relative price of non-tradable goods, instead of solely through the terms of trade. Importantly, this modification allows the model to extend to situations where a country does not consume any of its own export good.\footnote{The addition of a non-traded sector into the model of Galí and Monacelli (2005) has also been done in others (Corsetti, Dedola and Leduc, 2008; Santacreu, 2014; Guo, Ottonello and Perez, 2020).}

\footnote{The unmodified Galí and Monacelli (2005) model also yields the qualitative result of this model: nominal exchange rate movements can persist even after temporary foreign demand shocks.}
6.1 Households

The home economy is a small open economy, similar to the infinitesimally small open economy in Galí and Monacelli (2005). Asset markets are complete and labor is perfectly mobile across sectors.

Households have preferences described by the lifetime utility function

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t)$$

where $C_t$ denotes the consumption bundle and $L_t$ denotes hours worked in period $t$. Their specific period utility function is given by

$$U(C_t, L_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\psi}}{1+\psi}$$

Labor is divided among the home $H$ sector and the non-traded $N$ sector, such that $L_t = L_{NT,t} + L_{H,t}$. The consumption bundle is an aggregate of non-traded and traded consumption

$$C_t = \left( (1 - \lambda)^{\frac{1}{\nu}} C_{T,t}^{\frac{1}{\nu}} + \lambda^{\frac{1}{\nu}} C_{N,t}^{\frac{1}{\nu}} \right)^{\nu-1}$$

where $\lambda \in [0, 1]$ is the share of the non-traded good in consumption in steady state and $\nu > 1$ is the intertemporal elasticity of substitution between traded and non-traded goods.

In turn, traded consumption is a bundle of the home good and the foreign good

$$C_{T,t} = \left( (1 - \alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{1}{\eta}} \right)^{\eta-1}$$

where $\alpha \in [0, 1]$ can be seen as a measure for openness of the economy and $\eta > 1$ is the intertemporal elasticity of substitution between the home and foreign goods.
Optimal allocation of expenditure leads to the following price indices:

\[ P_t = \left( (1 - \lambda)P_{T,t}^{1-\nu} + \lambda P_{N,t}^{1-\nu} \right)^{\frac{1}{1-\nu}} \]

\[ P_{T,t} = \left( (1 - \alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta} \right)^{\frac{1}{1-\eta}} \]

Utility is subject to the following budget constraint, which assumes complete asset markets:

\[ P_tC_t + \mathbb{E}_t[F_{t+1}B_{t+1}] = B_t + W_tL_t + T_t \]

where \( F_t \) is the price of the one-period nominal bond, \( B_t \) is the number of bonds purchased in period \( t \), \( W_t \) is the wage, and \( T_t \) is a lump-sum transfer/tax. Note that there is a single wage in the economy because of perfectly mobile labor. Optimization subject to this constraint leads to the following log-linearized first order conditions:

\[ \sigma c_t + \psi \ell_t = w_t - p_t \]

\[ c_t = \mathbb{E}_t[c_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}] - \rho) \]

where \( \rho = -\log \beta \) is the rate of time preference, \( i_t = -\log F_t \) is the nominal interest rate, and \( \pi_{t+1} = p_{t+1} - p_t \) is CPI inflation. Lower case variables denote logs. The second of these two conditions is the Euler condition for nominal bonds.

6.2 Firms

Production for the two goods produced in the home economy takes the form

\[ y_{j,t} = a_{j,t} + \ell_{j,t} \quad j \in H, N \]
where \( a_{j,t} \) is the log of sector-\( j \) productivity. Firms minimize costs subject to this production function. The log-linearized first order condition is

\[
\begin{align*}
  w_t - p_{j,t} &= mc_{j,t} + a_{j,t} \quad j \in H, N
\end{align*}
\]

where \( mc_{j,t} \) denotes the marginal cost of sector \( j \). Each sector contains a continuum of firms, and each firm supplies their good via monopolistic competition. In other words, each firm sets its price by assuming it has a negligible effect on the price index and the demand schedule. Firms post their nominal price, and in each period a random fraction \( 1 - \theta \) of firms can reset their price to \( \bar{p} \). Firms choose their reset price in order to maximize profits today as well as in future states where they cannot reset their prices. Deriving the optimal price equation from the first order condition yields

\[
\bar{p}_{j,t} = (1 - \beta \theta) \sum_{k=0}^{\infty} \theta^k E_t[mc_{j,t+k}] \quad j \in H, N
\]

This leads to the following New Keynesian Phillips curve for each sector:

\[
\pi_{j,t} = \kappa mc_{j,t} + \beta E_t[\pi_{j,t+1}] \quad j \in H, N
\]

where \( \kappa = \frac{(1-\theta)(1-\beta \theta)}{\theta} \). Combining the firm’s first order conditions with the household’s first order conditions yields an expression for marginal cost:

\[
mc_{j,t} = \sigma c_t + \psi(y_t - a_t) - (p_{j,t} - p_t) - a_{j,t} \quad j \in H, N
\]

where

\[
a_t = (1 - \lambda)a_{H,t} + \lambda a_{N,t}
\]
6.3 Rest of the World

The rest of the world trades goods and financial securities with the home economy. They provide the foreign interest rate for nominal bonds, foreign demand for the home-produced export good, and a supply of the foreign-produced import good. Optimal foreign consumption of the home-produced export good will take the form

\[ C^*_H, t = \left( \frac{P^*_H, t}{P^*_t} \right)^{-\eta} Y^*_t \]

where \( P^*_H, t \) is the price of the export good in foreign currency, \( P^*_t \) is the foreign price index, and \( Y^*_t \) is a foreign demand shifter. Specifically, \( Y^*_t \) will be determined by an exogenous autoregressive process.

Because the home economy is so small, the rest-of-the-world economy will function essentially as a closed economy, consuming mostly its own foreign-made good \( F \). For this reason, its price index can be approximated with the price of the foreign good in foreign-currency terms:

\[ p^*_t = p^*_F, t \]

6.4 Exchange Rates and the Terms of Trade

Define the terms of trade \( S_t \) as the ratio of export prices to import prices:

\[ S_t = \frac{P^*_H, t}{P^*_F, t} \]

Taking logs and combining with the log-linearized price indices yields a relationship between inflation and the terms of trade:

\[ \pi_t = (1 - \lambda)(\pi_{H, t} - \alpha \Delta s_t) + \lambda \pi_{N, t} \]
Define the log real exchange rate $q_t$ as

$$q_t = e_t + p_t^* - p_t$$

where $e_t$ is the log nominal exchange rate. The law of one price holds for the foreign good:

$$p_{F,t} = e_t + p_{F,t}^* = e_t + p_t^*$$

Substituting the law of one price and the terms of trade definition into the real exchange rate definition yields a relationship between the real exchange rate and price levels of the consumption goods:

$$q_t = (\alpha(1 - \lambda) - 1)s_t + \lambda(p_{H,t} - p_{N,t})$$  \hspace{1cm} (7)

This shows how the real exchange rate moves with two sets of relative prices: the price of the home export good relative to the foreign import good (i.e. the terms of trade) and the price of the home export good relative to the non-traded good.

Substituting the law of one price into the terms of trade definition yields a relationship between the nominal exchange rate, the terms of trade, and the price of the export good.

$$s_t = p_{H,t} - e_t - p_{F,t}^*$$

Taking differences,

$$\Delta e_t = -\Delta s_t + \pi_{H,t} - \pi_{F,t}^*$$  \hspace{1cm} (8)

Importantly, this relationship is solely based on the law of one price and the terms of trade definition, not any other modeling assumptions. If the monetary authority is able to keep $\pi_{H,t} = 0$ and if the rest of the world has 0 inflation in the price of their good in foreign currency terms, i.e. $\pi_t^* = \pi_{F,t}^* = 0$, then the nominal exchange rate should appreciate one-for-one with terms of trade increases.
6.5 Risk sharing

Complete markets imply that the marginal utilities of consumption in the two countries, adjusted by the real exchange rate, should be equal:

\[ C_t = \vartheta C_t^* Q_t^{1\vartheta} \]

where \( \vartheta \) is a constant that depends on the initial conditions of the two countries’ relative net asset positions. Without loss of generality, assume \( \vartheta = 1 \).

Additionally, complete markets imply that the Uncovered Interest Parity holds:

\[ i_t - i_t^* = \mathbb{E}_t[\Delta e_{t+1}] \]

6.6 Monetary policy

I consider two alternative Taylor-type monetary policy rules: an export-price inflation targeting rule and a CPI inflation targeting rule.

\[ i_t = \rho + \phi \pi_{H,t} \]

\[ i_t = \rho + \phi \pi_t \]

6.7 Equilibrium

I define the competitive equilibrium as follows.

**Definition 1.** Given exogenous process \( Y_{F,t}^* \) and monetary policy rule \( i_t \), an equilibrium is a series of quantities \( \{Y_t, Y_{H,t}, Y_{N,t}, C_t, C_{H,t}, C_{N,t}, F_t, L_t, L_{H,t}, L_{N,t}\} \), prices \( \{W_t, P_t, P_{H,t}, P_{N,t}, P_{F,t}, E_t\} \), and interest rates \( \{i_t, i_t^*\} \) such that

1. Household optimization: Households’ choices solve their maximization problem given
the equilibrium prices and interest rate.

2. Firm optimization: Firms’ choices solve cost minimization.

3. Interest rates satisfy the UIP condition.

4. The price of the foreign tradable good $F$ satisfies the law of one price $P_{F,t} = E_t P^*_F$.

5. All markets clear.

6.8 Parameterization

The first set of parameters is set to the values in Gali and Monacelli (2005). These parameter values are shown in the first panel of Table 10. The second set is calibrated to the New Zealand economy, and the third set is calibrated to the US economy. Specifically, the share of non-tradable goods in New Zealand CPI comes from the expenditure weights in the CPI basket in 2011. The share of foreign goods in tradable consumption comes from a Reserve Bank of New Zealand note (Parker, 2014). The foreign demand shock parameters are calibrated by fitting an AR(1) process to log US GDP using quarterly, HP-filtered data from 1970 to 2019.

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39Because Gali and Monacelli (2005) do not include a non-traded good, they do not include a parameter for the intratemporal elasticity of substitution between traded and non-traded goods. However, I assume the intratemporal elasticity of substitution between traded and non-traded goods is the same as that between home-produced traded and foreign import goods.
### Table 10: Model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel 1: Parameters set following the literature</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Inverse intertemporal elasticity of substitution</td>
<td>1</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Inverse Frisch elasticity of labor supply</td>
<td>3</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Intratemporal elasticity of substitution, $H$ vs. $F$</td>
<td>1</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Intratemporal elasticity of substitution, $T$ vs. $NT$</td>
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</tr>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
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<tr>
<td>$\theta$</td>
<td>Calvo parameter</td>
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<tr>
<td>$\phi$</td>
<td>Taylor rule inflation coefficient</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Panel 2: Parameters calibrated to New Zealand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Fraction of foreign goods in tradable goods consumption basket</td>
<td>0.5</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Fraction of non-tradable goods in consumption basket</td>
<td>0.56</td>
</tr>
<tr>
<td><strong>Panel 3: Parameters calibrated to the US</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho_{Y^*}$</td>
<td>Foreign demand shock persistence</td>
<td>0.84</td>
</tr>
<tr>
<td>$\sigma_{Y^*}$</td>
<td>Foreign demand shock std.</td>
<td>0.013</td>
</tr>
</tbody>
</table>

### 6.9 Impulse Responses and Discussion

In order to examine the response to a foreign demand shock, I simplify the model to the case where productivity in both sectors is one and prices equalize between the two sectors. I examine the response to a 1 percent foreign demand shock for the export good. Results are shown in Figure 15.

As we can see, the immediate impact of the shock is a nominal exchange rate appreciation that moves one-for-one with the terms of trade. This causes CPI inflation to decrease as foreign goods become cheaper, so if the monetary authority targets CPI inflation, it temporarily lowers the nominal interest rate. Thus, while the real exchange rate returns to baseline, the nominal exchange rate remains appreciated. If the monetary authority targets export price inflation, they will not adjust the nominal interest rate. Rather, the UIP holds because the interest rate falls in the rest of the world in response to their demand shock.\(^{40}\)

It is straightforward to modify the model so that total exports $H$ are an aggregator of

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\(^{40}\)If the shock were instead to the foreign country’s preference parameter for good $H$, which is more applicable to my setting, the foreign interest rate would not change, and the domestic interest rate would need to adjust if the nominal exchange rate appreciation is not permanent.
two export goods: dairy and an additional export good, production of which is simply given by a constant endowment. If this is the case, then a foreign demand shock for dairy should impact the nominal exchange rate in the first period according to the proportion of dairy in total exports. Specifically, if dairy comprises 10% of the export sector, then a 1% rise in the terms of trade should cause a 0.1% nominal exchange rate appreciation. This is larger than the coefficient that I get in my elasticity estimates, leaving us with somewhat of a puzzle. The nominal exchange rate does move in the direction that theory suggests, though it does not in fact move as much as we would expect.
7 Conclusion

This paper provides causal evidence that terms of trade shocks do impact exchange rates. Specifically, in keeping with standard theory, export price increases cause exchange rate appreciations (and vice versa). The New Zealand setting serves as a well-identified natural experiment, but the result is important to all countries whose exports rely on a small number of commodities. As policymakers in these countries consider exchange rate policy, it is important for them to know the degree to which commodity prices will impact their exchange rate.

Additionally, this paper helps solve some of the exchange rate disconnect puzzle, providing evidence that a certain economic fundamental, namely the terms of trade, does causally impact exchange rates. The inability of the literature to decisively prove such relationships has slowed theoretical research in the field. This paper demonstrates how well-identified natural experiments can help progress our understanding of exchange rate determination, and seeking out additional natural experiments may continue to be a fruitful avenue for future research.
References


Santacreu, Ana Maria. 2014. “Reaction functions in a small open economy: What role for non-traded inflation?”


A Additional Figures

Figure 16: Surprise metric over time

![Figure 16: Surprise metric over time](image1)

Figure 17: Distribution of surprise metric

![Figure 17: Distribution of surprise metric](image2)
B Robustness Checks

My baseline specification for the elasticity of the exchange rate to surprise changes in WMP prices is given in Table 4. Here, I show a few modifications to my preferred specification. Estimates are remarkably consistent.

First, instead of calculating cumulative abnormal returns, I calculate cumulative returns. That is, I do not subtract the mean return in the estimation window. This specification does not take into account the possibility of an underlying trend in the exchange rate returns due to perhaps some other event around the auction. Results are shown in Table 11. The point estimates are only 0.001 lower than when I calculate cumulative abnormal returns.

Second, I consider the fact that surprises are somewhat auto-correlated, and I use Newey-West standard errors. Table 12 shows that results remain significant at the 5% level.

Third, I take a subsample of the data, only considering dates before the Insights package was released on February 16, 2016. This package allows non-auction participants to purchase access to auction information during the event. The existence of this product means that exchange rates may adjust over the course of the event instead of reacting suddenly when the final price is announced publicly at the end of the auction. This would bias my estimates.
Table 11: Elasticity estimates, calculated with cumulative returns instead of cumulative abnormal returns

<table>
<thead>
<tr>
<th></th>
<th>Cumulative $\Delta e$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) NZD/USD</td>
</tr>
<tr>
<td>Surprise $\Delta$ WMP</td>
<td>$-0.009^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
</tr>
<tr>
<td>Expected $\Delta$ WMP</td>
<td>$-0.005^{**}$</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
</tr>
<tr>
<td>R2</td>
<td>0.094</td>
</tr>
</tbody>
</table>

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Coefficients displayed with standard errors in parentheses.

Towards 0. However, Table 13 shows that the estimates from the earlier subsample are almost identical to the entire subsample, differing by only 0.001.

Forth, I consider only auctions that were second in the month. Recall that WMP futures settle to the average auction price of the two auctions in a given month. Calculating the expected auction price ahead of the second auction in a month requires no assumptions, since the first price was already determined; however, in order to calculate the expectation ahead of the first auction, I assume that market participants expect the same price for the two auctions that month. This assumption is born out by the data, but for robustness I run my baseline regression, subsampling dates into whether they were the first or second auction in the month ($n = 1, 2$). Table 14 shows that point estimates are actually larger when I only consider the first auction each month, which is surprising. However, after further analysis, it seems that this behavior may be driven by outliers. When I winsorize the surprise metric at the 5th and 95th percentiles, I recover estimates for each surprise group that are much more similar to my baseline estimates.

Finally, I consider surprises in both whole milk powder (WMP) and skim milk powder
Table 12: Elasticity estimates, adjusting for auto-correlation in surprises

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/USD</th>
<th>(2) NZD/USD</th>
<th>(3) NZD/AUD</th>
<th>(4) NZD/AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise ∆ WMP</td>
<td>−0.010**</td>
<td>−0.012**</td>
<td>−0.009**</td>
<td>−0.011***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.004)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>Expected ∆ WMP</td>
<td>−0.004</td>
<td></td>
<td>−0.005**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
<td>209</td>
<td>212</td>
<td>209</td>
</tr>
<tr>
<td>R2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with Newey-West standard errors in parentheses.

... (SMP) prices. Because SMP futures were not started until March 2011, this analysis includes a slightly smaller sample. WMP and SMP surprises are 43% correlated, though they only have the same sign 71% of the time. This means that on 29% of dates, WMP is more expensive than expected while SMP is less expensive than expected, or vice versa. I do not consider butter or AMF, the other two products with futures, due to the low traded volume of the NZX futures and the added complication that the same product can be sold in either format, making supply forecasts in each product unstable.

I use two methods to examine the exchange rate response to both WMP and SMP price surprises. First, I regress cumulative abnormal exchange rate returns on WMP and SMP prices separately. Table 16 shows that only the coefficient on WMP surprises is significant. While I want to be careful interpreting this, due to the correlation between WMP and SMP surprises, it would make sense that the market is responding to the price changes in the product that makes up the larger portion of the export index. In 2010, New Zealand exported three times as much WMP as SMP. Interestingly, Bloomberg only releases headlines when WMP prices are announced, not SMP prices. Second, I create a blended surprise measure, in which I then combine the SMP and WMP surprises using weights equal to total exports of

41 The relevant SMP contract for the forwards contract is medium heat of New Zealand origin.
Table 13: Elasticity estimates for the subsample of dates before the Insights package was released on February 16, 2016

<table>
<thead>
<tr>
<th></th>
<th>Cumulative abnormal $\Delta e$</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) NZD/USD</td>
<td>(2) NZD/USD</td>
<td>(3) NZD/AUD</td>
<td>(4) NZD/AUD</td>
</tr>
<tr>
<td>Surprise $\Delta$ WMP</td>
<td>$-0.009^{***}$ (0.003)</td>
<td>$-0.013^{***}$ (0.003)</td>
<td>$-0.009^{***}$ (0.002)</td>
<td>$-0.012^{***}$ (0.002)</td>
</tr>
<tr>
<td>Expected $\Delta$ WMP</td>
<td>$-0.009^{***}$ (0.003)</td>
<td>$-0.009^{***}$ (0.003)</td>
<td>$-0.008^{***}$ (0.002)</td>
<td>$-0.008^{***}$ (0.002)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.000 (0.000)</td>
<td>0.000 (0.000)</td>
<td>0.000 (0.000)</td>
<td>0.000 (0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>122</td>
<td>120</td>
<td>122</td>
<td>120</td>
</tr>
<tr>
<td>R2</td>
<td>0.085</td>
<td>0.153</td>
<td>0.161</td>
<td>0.253</td>
</tr>
</tbody>
</table>

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Coefficients displayed with standard errors in parentheses.

each product in 2010. Table 17 shows that the elasticity of the exchange rate to this blended measure is almost identical to the elasticity when I only consider WMP price surprises.

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Table 14: Elasticity estimates depending on auction number in a month

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/USD n=1</th>
<th>(2) NZD/USD n=2</th>
<th>(3) NZD/AUD n=1</th>
<th>(4) NZD/AUD n=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise Δ WMP</td>
<td>−0.015***</td>
<td>−0.006**</td>
<td>−0.013***</td>
<td>−0.007***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>103</td>
<td>109</td>
<td>103</td>
<td>109</td>
</tr>
<tr>
<td>R2</td>
<td>0.151</td>
<td>0.049</td>
<td>0.252</td>
<td>0.112</td>
</tr>
</tbody>
</table>

* *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01. Coefficients displayed with standard errors in parentheses.

Table 15: Elasticity estimates depending on auction number in a month, after winsorizing observations at the 5th and 95th percentiles

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/USD n=1</th>
<th>(2) NZD/USD n=2</th>
<th>(3) NZD/AUD n=1</th>
<th>(4) NZD/AUD n=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise Δ WMP</td>
<td>−0.014***</td>
<td>−0.011**</td>
<td>−0.015***</td>
<td>−0.009***</td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Constant</td>
<td>−0.000</td>
<td>−0.000</td>
<td>−0.000</td>
<td>−0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>94</td>
<td>97</td>
<td>94</td>
<td>97</td>
</tr>
<tr>
<td>R2</td>
<td>0.077</td>
<td>0.065</td>
<td>0.199</td>
<td>0.071</td>
</tr>
</tbody>
</table>

* *p* < 0.1, ** *p* < 0.05, *** *p* < 0.01. Coefficients displayed with standard errors in parentheses.
Table 16: Elasticity estimates taking WMP and SMP surprises into account

<table>
<thead>
<tr>
<th>Cumulative abnormal $\Delta e$</th>
<th>(1) NZD/USD</th>
<th>(2) NZD/USD</th>
<th>(3) NZD/AUD</th>
<th>(4) NZD/AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise $\Delta$ WMP</td>
<td>$-0.011^{***}$</td>
<td>$-0.012^{***}$</td>
<td>$-0.010^{***}$</td>
<td>$-0.012^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Surprise $\Delta$ SMP</td>
<td>0.002</td>
<td>0.001</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Expected $\Delta$ WMP</td>
<td>$-0.004$</td>
<td></td>
<td>$-0.006^{***}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Expected $\Delta$ SMP</td>
<td>$-0.001$</td>
<td></td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>203</td>
<td>200</td>
<td>203</td>
<td>200</td>
</tr>
<tr>
<td>R2</td>
<td>0.100</td>
<td>0.114</td>
<td>0.180</td>
<td>0.198</td>
</tr>
</tbody>
</table>

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Coefficients displayed with standard errors in parentheses.

Table 17: Elasticity estimates to a blended metric of WMP and SMP price surprises

<table>
<thead>
<tr>
<th>Cumulative abnormal $\Delta e$</th>
<th>(1) NZD/USD</th>
<th>(2) NZD/USD</th>
<th>(3) NZD/AUD</th>
<th>(4) NZD/AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise $\Delta$ WMP+SMP</td>
<td>$-0.010^{***}$</td>
<td>$-0.012^{***}$</td>
<td>$-0.009^{***}$</td>
<td>$-0.010^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Expected $\Delta$ WMP</td>
<td>$-0.002$</td>
<td></td>
<td>$-0.004^{**}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Expected $\Delta$ SMP</td>
<td>$-0.004$</td>
<td></td>
<td>$-0.001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td></td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>203</td>
<td>200</td>
<td>203</td>
<td>200</td>
</tr>
<tr>
<td>R2</td>
<td>0.077</td>
<td>0.099</td>
<td>0.133</td>
<td>0.149</td>
</tr>
</tbody>
</table>

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Coefficients displayed with standard errors in parentheses.
C Tests of the Financial Flows Mechanism

In this section, I show two tests of the financial flows mechanism. Both are weak tests in that significant results would provide evidence for the financial flows mechanism, but the lack of significant results is not informative.

One of the testable predictions of the Gabaix and Maggiori (2015) model is that covered interest rate parity (CIP) deviations should arise as long as the financier’s risk-bearing capacity is not a function of exchange rate volatility. The fact that CIP deviations have become a barometer of flow pressures can be seen in the positive correlation of CIP deviations with broad US Dollar strength since the global financial crisis in 2008 (Engel and Wu, 2018; Jiang, Krishnamurthy and Lustig, 2021). Because CIP deviations can be easily calculated from contemporary market prices, I can examine the high-frequency response of CIP deviations to surprise WMP price changes. A systematic response in CIP changes would provide evidence in favor of this flow mechanism. However, since CIP deviations do not need to arise under the mechanism, and indeed would not arise if risk-bearing capacity is a function of exchange rate volatility, the lack of response does not provide evidence against the mechanism.

The 3-month CIP deviation between government bond yields in the United States and New Zealand is defined as

$$\Phi_{3m,t} = i_{3m,t}^{NZ} - i_{3m,t}^{US} - \rho_{3m,t}^{USD/NZD} = i_{3m,t}^{NZ} - i_{3m,t}^{US} - \frac{1}{n}(f_{3m,t}^{USD/NZD} - e_t^{USD/NZD})$$

where $f_{3m}$ is the log 3-month forward exchange rate, $\rho$ is the forward premium, and $n$ is the tenor of the bonds and the forward rate in years. Because of my finding that interest rates do not seem to move with WMP price surprises, I can examine whether the forward

---

42Specifically, CIP fails in the Gabaix and Maggiori (2015) model when their $\alpha = 0$. 

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premium changes with WMP price surprises:

\[ \Delta \rho_{3m,a}^{USD/NZD} = \alpha + \beta s_a + \varepsilon_a \]

Results are shown in Table 18.\textsuperscript{43} It appears CIP deviations do not change after WMP price surprises.

Table 18: The impact of surprise WMP changes on the CIP wedge within 15 minutes after the announcement

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise ∆ WMP</td>
<td>−0.000</td>
<td>−0.000</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Expected ∆ WMP</td>
<td></td>
<td>−0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>Constant</td>
<td>(1.040 \times 10^{-06})*</td>
<td>(1.272 \times 10^{-06})**</td>
</tr>
<tr>
<td></td>
<td>((5.659 \times 10^{-07}))</td>
<td>((5.720 \times 10^{-07}))</td>
</tr>
<tr>
<td>Observations</td>
<td>212</td>
<td>209</td>
</tr>
<tr>
<td>R2</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* \(p < 0.1\), ** \(p < 0.05\), *** \(p < 0.01\). Coefficients displayed with standard errors in parentheses.

Figure 19 shows how the entire term structure of the forward rate shifts. Following Du, Im and Schreger (2018) and Du, Tepper and Verdelhan (2018), I calculate the forward premium for maturities greater than or equal to one year as

\[ \rho_{n,t}^{USD/NZD} = i_{rs_{n,t}}^{NZ} + b_{n,t}^{NZ} - i_{rs_{n,t}}^{US} \]

where \(i_{rs_{n,t}}^{NZ}\) denotes the \(n\)-year interest rate swap that exchanges a fixed cashflow in New Zealand Dollars into the New Zealand 3-month bank bill, \(i_{rs_{n,t}}^{US}\) denotes the \(n\)-year interest rate swap that exchanges a fixed cashflow in US Dollars into 3-month US Libor, and \(b_{n,t}^{NZ}\) denotes the \(n\)-year cross-currency basis swap that exchanges the New Zealand 3-month bank

\textsuperscript{43}In calculating cumulative abnormal returns of the forward premium, I use high-frequency data at the 5-minute level instead of the 1-minute level.
bill for 3-month US Libor.\textsuperscript{44} From this forward premium, I then back out the effective forward rate for various maturities, and I compare changes in these forward rates to WMP price surprises.

\[ \Delta f_{r,a}^{USD/NZD} = \alpha + \beta s_a + \varepsilon_a \]

I also look at how forward premiums of various tenors respond to WMP price surprises.

\[ \Delta \rho_{r,a}^{USD/NZD} = \alpha + \beta s_a + \varepsilon_a \]

Since the New Zealand interest rate swap and basis swap are not liquid during the overnight auctions, I examine daily changes to the effective forward rate. I graph the coefficients for these regressions in Figure 19. We can see from the figure that the spot and 3-month forward coefficient estimates are very close to my high-frequency estimates, though standard errors are much larger. None of the forward premiums seem to respond to surprise WMP price changes, and most of the forward rate term structure shifts by similar amounts. The 7- and 10-year tenors shift by less because the formula for the forward rate places a weight on the forward premium equal to the tenor in years.

I next ask whether exchange rate movements are primarily happening when financiers are likely to be constrained. If financiers already hold risk on their books before a New Zealand Dollar demand shock, they are more likely to hit bank-imposed risk limits. Specifically, if financiers are already long the New Zealand Dollar, and if WMP prices then increase prompting demand for the New Zealand Dollar, then financiers will be less able to meet this demand, causing a nominal exchange rate appreciation. Thus, if this flow story is driving the exchange rate response, the New Zealand dollar should be more likely to appreciate after surprise WMP price increases on days when financiers are already long the New Zealand dollar. Similarly, it should be more likely to depreciate after surprise WMP price decrease.

\textsuperscript{44}This is the conventional way to calculate forward premiums for maturities greater than or equal to one year, since outright forwards in these maturities are highly illiquid.
Figure 19: The effect of surprise increases in WMP prices on the USD/NZD forward rates and forward premiums of various tenors

(a) Forward rates

(b) Forward premiums

Note: Bars denote 95% confidence intervals.

on days when financiers are already short the New Zealand dollar.\textsuperscript{45} However, if the New Zealand Dollar is just as likely to appreciate when financiers are short and depreciate when financiers are long, this would provide evidence against the flow mechanism in this context.

In order to test whether these financial constraints seem to be relevant, I split my sample according to whether surprises were positive or negative and whether financiers were long or short New Zealand Dollar exchange-traded futures and options before the auction. Positioning data comes from the Commitments of Traders (COT) Reports, released by the Commodity Futures Trading Commission (CFTC), and is based on futures and options position data supplied for reporting firms.\textsuperscript{46} The COT reports include a breakdown by a trader’s type, with one of these types being “dealer/intermediary.” This category aligns with the Gabaix and Maggiori (2015) definition of financier, so I use the data from this category. The data is collected once a week, and in order to make sure I’m using dealer positions from

\textsuperscript{45}When a financier is “long” the New Zealand Dollar, they profit when the New Zealand Dollar appreciates. When they are “short” the New Zealand Dollar, they profit when the New Zealand Dollar depreciates.

\textsuperscript{46}Reporting firms include futures commission merchants, clearing members, foreign brokers and exchanges. Specifically, the COT reports detail the aggregate open interest for futures and options in markets where at least 20 traders hold a position above a given reporting level.
before the auction, I use the last positioning report before the day of the auction (i.e., if positioning is reported on auction day, I use the positioning from the previous week).

Table 19 shows my results. The point estimates are consistent across all columns, showing that the exchange rate responds with the same elasticity to surprise WMP price shocks regardless of whether financiers were positioned in the same or opposite direction of the ultimate exchange rate movement in exchange-traded markets. However, while these COT reports represent the best publicly available data on financier positioning, they leave out the more relevant over-the-counter spot and forward markets. Combined with the fact that market participants are incentivized to obscure activity that makes their positions publically known, this makes my test a weak one. In particular, if I had found that exchange rate movements are driven by days when financiers already hold a certain direction of risk in the over-the-counter markets on their books, this would have provided evidence for the financial flows mechanism. However, not finding this result may only indicate that financier positions are primarily taken in over-the-counter markets.
Table 19: The impact of surprise WMP changes on the New Zealand Dollar within 15 minutes after the announcement and depending on whether dealers were long or short the New Zealand Dollar in the days before the announcement

<table>
<thead>
<tr>
<th></th>
<th>(1) NZD/USD</th>
<th>(2) NZD/USD</th>
<th>(3) NZD/AUD</th>
<th>(4) NZD/AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise Δ WMP</td>
<td>−0.010***</td>
<td>−0.010***</td>
<td>−0.010***</td>
<td>−0.009***</td>
</tr>
<tr>
<td>Constant</td>
<td>−0.000</td>
<td>0.000</td>
<td>−0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Observations</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>106</td>
</tr>
<tr>
<td>R2</td>
<td>0.083</td>
<td>0.100</td>
<td>0.164</td>
<td>0.180</td>
</tr>
</tbody>
</table>

* p < 0.1, ** p < 0.05, *** p < 0.01. Coefficients displayed with standard errors in parentheses.

Note: “same posn” indicates days where dealers were long the New Zealand dollar before a positive price surprise or short the New Zealand dollar before a negative price surprise. The increased flow from the price change would cause dealers to take more of the same position that they already had on their books, which would be more likely to cause them to hit risk limits and become constrained. “opposite posn” indicates days where dealers were short the New Zealand dollar before a positive price surprise or long the New Zealand dollar before a negative price surprise. The increased flow from the price change would cause dealers to take an opposite position from what they already had on their books.