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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 percent of exports. Specifically, whole milk powder accounts for 6 to 11 percent 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 percent 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 a fundamental channel. The methodology developed here can potentially be applied to other commodity exporters.

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This paper presents preliminary analysis and results intended to stimulate discussion and critical comment. The views expressed herein are those of the authors and do not indicate concurrence by the Federal Reserve Bank of Boston, the principals of the Board of Governors, or the Federal Reserve System.

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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 amid a natural experiment. Theoretically, terms of trade increases should cause nominal exchange rate appreciations via the consumer price index (CPI) and price stickiness. The nominal exchange rate may also appreciate if a shock induces increased demand for the currency or if the central bank increases 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.

This effect is of interest especially to economies that rely on the export of a single commodity. How does the Chilean peso respond to copper price movements? How does the Russian ruble respond to oil price movements? Despite the widespread relevance of this question, many economies may struggle to identify a causal link if they focus internally. Because these countries often export a significant portion of world supply, they are not necessarily price takers. Thus, there may be confounding variables that affect both the price of the commodity via domestic supply and the exchange rate via the domestic CPI. In order to identify a causal link between an export commodity and an exchange rate, we need to be able to find and measure shocks to external demand for the commodity, which are exogenous to the domestic economy. The dairy auctions of New Zealand constitute a natural experiment that provides such an opportunity.

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). Similar to other settings with a primary commodity export, these auctions involve 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 percent of the country's exports, and WMP makes up 6 to 11 percent of total exports.[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 with a magnitude large enough to detect.

While there are multiple countries for which a single commodity makes up a large percentage of the export basket (for example, copper in Chile or soy in Brazil), two unique factors in the New Zealand setting allow me to measure exogenous shocks to its primary commodity. First, WMP prices are announced at 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 the actual price ranging from 19 percent below to 33 percent above the expected price.

Second, surprises at these auctions are due to factors exogenous to the New Zealand

[2]More specifically, it made up 6 to 11 percent of total exports during the 2010–2019 period.

economy. Supply is announced a few days in advance, so surprises are determined by foreign demand. These demand shocks arise at the auction because a subset of buyers is excluded from the futures market due to capital controls and size limitations. Furthermore, I show that these demand shocks are dairy-specific and not indicative of changes to foreign income. These two ingredients 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 in 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 narrow window. Within the 15 minutes after WMP price shocks, the exchange rate appreciates about 0.01 percent for a 1 percent surprise increase in WMP prices, which is directionally in line with theoretical expectations.

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 smaller than theory suggests. Specifically, I would expect the nominal exchange rate to initially appreciate about 1-for-1 with terms of trade increases. This prediction follows from the law of one price and a mechanism that allows the price of the export good to impact the CPI (even if the home country does not consume its own export good, its price can feed into the price of other goods via either an endowment effect or mobile factors of production).[3] Because WMP makes up 6 to 11 percent of New Zealand's total exports over the course of my study, I would expect the exchange rate to appreciate about 0.06 to 0.11 percent for a 1 percent surprise increase in WMP prices.

Terms of trade shocks can affect the nominal exchange rate through two mechanisms, in addition to this "fundamental" mechanism. First, the monetary authority may change its policy rate in response to the impact of export price shocks on aggregate demand. The

[3]The exact response of the nominal exchange rate depends on the monetary policy rule, as illustrated in the appendix with a small open-economy model in the style of Galí and Monacelli (2005).

nominal exchange rate would then adjust via uncovered interest parity (UIP). Second, the nominal exchange rate also would adjust 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. These two mechanisms are relevant only 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, as the effect is about 10 times larger than we would expect given the size of the financial flow. Rather, the nominal exchange rate movement seems to be driven by a combination of the financial flows and fundamental mechanisms. In the appendix, I model the fundamental mechanism by adding a non-traded sector to the Galí and Monacelli (2005) model. Impulse responses that are created 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 exchange 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, the existing literature finds conflicting results around whether commodity price changes induce exchange rate movements. Because my paper relies on an identification strategy that is stronger than those 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 predictions.

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 do not look into terms of trade shocks; instead, they focus on either announcements of measures such as GDP and CPI or 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 fundamental response to domestic price shifts. Section 6 concludes.

2 Setting and the Relevance of GDT Auctions

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 dairy items: whole milk powder (WMP), skim milk powder (SMP), butter, anhydrous milk fat (AMF), butter milk powder, cheddar, lactose, and sweet whey powder.[4] As discussed, dairy is New Zealand's largest export good category.[5] In fact, three of the four largest dairy items traded in the GDT auctions accounted for 10 to 16 percent of New Zealand's goods and services exports during the 2010–2018 period (Figure 2), with whole milk powder (WMP) alone accounting for 6 to 11 percent.[6] This makes WMP New Zealand's single largest export, outside of the services sector, which is why I focus on WMP throughout this paper.[7]

GDT auctions are held twice a month. They were 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 serve their intended purpose of providing reference prices. As Figure 3 shows, the price of WMP sold at GDT auctions is highly predictive of the WMP export price index published by New Zealand's official data agency.[8] The lag appears because shipments occur after the auction date, and much of the visual difference in the two series is due

[4]Each item trades for multiple contract periods, which refer to the month when the good will ship. For example, contract period 2 (CP2) means that the product ships two months after the auction. A CP2 good traded in a May auction, for example, ships in July. The contract period definitions changed before the second auction in September 2011. Previously, a CP1 good shipped in the second month after the auction.

[5]From 2010 to 2014, dairy was the largest export category, including services. From 2015 to 2019, it was surpassed only by travel and tourism.

[6]The four largest dairy items are WMP, SMP, butter, and AMF. I have export data for only WMP, SMP, and butter because AMF is combined into a category with other goods.

[7]Specifically, I focus on the contract specification CP2 for regular WMP sourced in New Zealand. I also include SMP in robustness checks in Appendix A. I do not consider butter or AMF, the other two dairy products with New Zealand's Exchange (NZX) futures, due to the low traded volume of the futures and the added complication that AMF and butter are essentially the same product sold in two different formats, making supply forecasts for each product unstable.

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

to the fact that the WMP export price index is released quarterly, while the auction price is updated twice a month. In fact, from 2010:Q4 through 2019:Q4 the two series were 88 percent correlated, adjusting for shipping lags.[9] 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.[10]

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.

For all of these reasons, market participants watch GDT auctions as an indicator of export prices. This is exemplified in the following excerpt from a June 15, 2015, *Wall Street Journal* article 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.*

Market participants' perception of a link between GDT auctions and export prices is discussed even more explicitly in an August 5, 2014, *Wall Street Journal* article titled "International Dairy Prices Tumble":

> *The Global Dairy Trade auction is closely watched as the GDT Price Index is widely*

[9]Other discrepancies between the two series arise because not all WMP powder was sold at GDT auctions during this period. However, much of the off-auction sales happen in the 24 hours after the auction at the GDT auction price. In fact, all of Fonterra's non-GDT sales are linked to the GDT price, with different customers priced at a specified additive spread to the GDT price. This is economically significant in its own right, as Fonterra produces more than 80 percent of New Zealand's dairy, and anecdotally the same is true for certain other New Zealand WMP exporters.

[10]From 2012 through 2016, GDT was the only price source for WMP, SMP, and AMF in the farmgate milk price calculation. Beginning in 2017, certain off-GDT sales were included; however, Fonterra notes in its 2019 farmgate milk price statement that including off-GDT sales increased the farmgate milk price by only 1.6 percent relative to not including these off-GDT sales.

considered a market reference price for dairy products.

3 Empirical Approach for Elasticity Identification

Conceptually, export price shocks should impact the nominal exchange rate via the domestic consumer price index (CPI) and sticky prices. Export prices may feed through to the prices of other domestically produced goods in the CPI due to either the income windfall or mobile factors of production. The nominal exchange rate may also respond to an export price shock if the shock induces a change in demand for the currency, or if it prompts a change to the policy rate.

To estimate the extent to which WMP price movements affect the nominal exchange rate, I consider a regression of the form

$$\Delta e_a = \alpha + \beta \Delta p_a^{WMP} + \varepsilon_a, \tag{1}$$

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.[11] Since export price increases should cause local currency appreciations (and since a positive movement in e indicates a local currency *depreciation*), we should expect β to be negative. To precisely identify the coefficient, I calculate Δe_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.[12] Thus, prices are revealed at a 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

[11] Although p^{WMP} should ideally be in local currency, WMP is sold in US dollars, so I will consider percentage changes in US dollar terms. However, when I convert $\hat{\beta}$ to reflect price changes in New Zealand dollar terms, the coefficient will be quite similar.

[12] Starting with the February 16, 2016, auction, GDT sold real-time access to auctions via its "Insights" package. I exclude auctions after this date in Appendix A.

containing the auction results.[13] These Bloomberg headlines alert foreign exchange market participants as soon as GDT publishes the prices.[14] Minute-by-minute exchange rate data come from histdata.com.

My event window includes the five minutes before the announcement time through the 15 minutes after the announcement, in keeping with the literature (for example, Faust et al., 2007). Using such a narrow window reduces outside noise, allowing me to isolate the impact of price announcements on the exchange rate. I assume that all other variables are fixed during this window. I calculate the cumulative abnormal exchange rate return by comparing the cumulative returns during the event window with 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 United States and Australia are the two countries with floating currencies that import the most dairy from New Zealand (Figure 5). Although 18 percent of New Zealand dairy exports and 32 percent of New Zealand WMP exports go to China, I don't consider the Chinese renminbi, because I don't have high-frequency data on its exchange rate.[15] Summary statistics for the relevant exchange rates during the sample period are given in Table 1.

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 cause the exchange rate to vary only if the announced price differs

[13]There are five days when the headline does not appear to be available on Bloomberg: February 18, 2014; March 4, 2014; April 1, 2014; January 2, 2019; and March 5, 2019. I exclude these days from my high-frequency analysis.

[14]Starting with the September 16, 2014, auction, Bloomberg automated this headline release.

[15]Because WMP is such a small portion of these foreign economies, it doesn't necessarily matter which NZD exchange rate we look at, as we wouldn't expect bilateral foreign exchange rates to move with a WMP price shock. For example, even if the CNY exchange rate were not fixed, we would not expect the CNY/USD exchange rate to move due to WMP auction announcements, so the CNY/NZD and USD/NZD exchange rate movements should be equivalent.

from the expected price. Thus, the relevant regression to identify β is:

$$\Delta e_a = \alpha + \beta s_a + \varepsilon_a, \tag{2}$$

where s denotes the surprise component of the announcement. Quantifying the response requires the ability to calculate the expected WMP price and how it differs from the actual WMP price.

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.[16] 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 at that auction. If I assume futures market participants are risk-neutral and have rational expectations, then the expected auction prices at auction $n \in \{1, 2\}$ of month m, which is on day t, is given by:

$$\mathbb{E}_{t-1}(P^{n=1,m}_{WMP,t}) = F^{m}_{WMP,t-1}$$

$$\mathbb{E}_{t-1}(P^{n=2,m}_{WMP,t}) = 2 \times F^{m}_{WMP,t-1} - P^{n=1,m}_{WMP},$$

where P_{WMP} denotes the WMP auction price, and $F_{WMP,t-1}$ 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.[17] Daily

[16] In keeping with the contract period definition change in September 2011, the futures settled to the CP1 price up through the September 6, 2011, auction.

[17] As a robustness check in the appendix, I use only the subset of auctions that were second in the month.

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 eight- to nine-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 information after the futures market closing time (Figure 6 clarifies this timeline).

Given the expected WMP price, I can back out the surprise component of the WMP auction price for an auction a:[18]

$$s_a = \ln(P_a^{WMP}) - \ln(\mathbb{E}_{t-1}(P_a^{WMP})). \tag{3}$$

Specifically, s measures the percentage 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 2. A few notable features stand out. First, the mean of the surprise metric is very close to zero (though a 95 percent confidence interval around the mean does not include zero). Second, the surprises can be quite large, from 33 percent more than the expected price to 19 percent less than the expected price. Figure 7 shows a graph of the surprise metric over time, and Figure 8 shows its distribution.

This empirical set-up enables the calculation of 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, that is, that auction surprises affect the New Zealand dollar

[18]There are four days when GDT did not publish WMP prices: July 15, 2015; August 4, 2015; November 3, 2015; and 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 auctions in August 2015, November 2015, and March 2017, I calculate the expected auction price as

$$\mathbb{E}_{t-1}(P_{WMP,t}^{n=2,m}) = F_{WMP,t-1}^{m}$$

only 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 affect 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 be due solely to price changes in WMP, and I would misidentify β.

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 to 100 percent of the whole milk powder sold, and it publishes auction supply forecasts three trading days before the auction. As Figure 9 shows, auction supply rarely deviates from the published forecasted amount. Specifically, on 94 of the 188 days for which I have the supply forecast, the supply was exactly equal to the forecasted supply, and the appendix shows how my baseline estimates do not change when I restrict my sample to days when supply was perfectly predicted. Overall, the mean squared error of using these forecasts to predict supply is 469 metric tons (MT), which is 3 percent of the average quantity sold (18,076 MT). Thus, any auction surprises must come from buyer demand.[19]

Therefore, the exclusion restriction holds as long as auction demand affects the New Zealand economy (in particular, the price of the consumption basket) only through auction surprises. 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 percent of the WMP produced by Fonterra is consumed domestically, so it should follow that a similarly small share of the product sold at GDT auctions is sold to domestic buyers.[20] While the amount demanded by each

[19] 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 its total supply at GDT auctions. While the amount that Fonterra sells at GDT auctions ranges from 18 to 32 percent annually over the course of my study, this proportion is auto-correlated on a quarterly basis. The auto-correlation coefficient is 0.56, which is significant at the 0.001 percent level. Note that the auction price is based on the matching of auction demand to auction supply. Additionally, many of the off-auction sales are made within the 24-hour period at a prespecified spread to the GDT auction price.

[20] Anecdotally, the percentage sold domestically at GDT auctions is quite smaller.

country is not public, north Asia, which includes China, accounts for the majority of demand (Figure 10). It receives 55 percent of all WMP auction supply on average over the course of my sample, though this amount is highly variable, ranging from 12 to 91 percent with an overall standard deviation of 15.7 percent (Table 3).[21]

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 serve only clients of a certain size, and none of the 50 official global Fonterra resellers that buy on the GDT platform is large enough to work with these brokers. Thus, demand shocks from these participants will be revealed at auction, enabling auction price surprises.

Although demand comes primarily from 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 foreign buyers have private information about future New Zealand supply, especially since futures market participants include New Zealand dairy suppliers. Actors from across the entire WMP supply chain participate in the WMP futures market, including companies with contracts that link prices to the GDT auctions but that have not been approved to participate in GDT auctions.[22] This includes certain non-Fonterra dairy blenders and processors in New Zealand that sell abroad. It

[21]In an interview with me, a former dairy analyst for NZX noted, "Demand is driven by a small number of Chinese buyers."

[22]NZX has a separate futures product geared toward farmers that settles to a New Zealand dollar price referencing 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.

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. As long as the impact of future domestic supply on demand is fully reflected in futures prices, it should not affect the surprise metric, and the exclusion restriction should hold.

Fonterra also forecasts supply for an additional four auctions (over the ensuing two months) when it forecasts supply for the upcoming auction. Thus, all market participants know Fonterra's forecasts for the next two months of auctions a few days before each auction, and futures markets should take this information into account. Figure 11 shows that Fonterra's two-month ahead forecasts are not as reliable predictors of actual auction supply,[23] but it seems fair to say buyers and futures markets have the same information about supply for as many as five auctions ahead.

The second worry is somewhat mitigated by the fact that dairy accounts for only a small portion of the Chinese economy. Dairy constituted only 0.3 percent of total Chinese imports in 2018 and only 0.4 percent of Chinese GDP in 2017. However, this does not eliminate the worry; one could imagine a story where greater 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

[23] The mean squared error (MSE) of using these forecasts to predict supply is 4,121 MT, almost nine times the MSE of the final forecast.

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 4 shows, I find that this is not the case: None of these other currencies or commodities reacts to milk price shocks, providing evidence for the exclusion restriction.[24]

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 $\mathbb{E}_{t-1}(P_a^{WMP})$, 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 $\mathbb{E}_{t=0}(P_{t=1})$, 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 (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 difficult 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

[24] Even if WMP price surprises did reveal information about Chinese growth, a weaker exclusion restriction that auction surprises affect the New Zealand dollar only 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.

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 due to either 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, the results from which may be applied to other commodity-producing countries.

4 Results of Elasticity Identification

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 then examining whether the exchange rate responds differently on the three categories of days. Figure 12 shows that on auction days with negative WMP price surprises, the New Zealand dollar tends to depreciate immediately following the announcement, whereas on auction days with positive WMP price surprises, the New Zealand dollar tends to appreciate immediately following the announcement. Figure 13 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.

I report my results for my baseline specification (Equation 2) in Table 5. Columns 1 and 3 show that the New Zealand dollar appreciates 0.010 percent against the US dollar and 0.009 against the Australian dollar for a 1 percent increase in the surprise component of WMP auction prices (a decrease in the exchange rate denotes an appreciation).[25] This

[25]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 percent increase in USD WMP prices, the exchange rate appreciates 0.01 percent, and NZD WMP prices increase by 1.01 percent. Thus, the exchange rate appreciates $\frac{0.01}{1.01} = 0.0099\%$ for a 1 percent increase in NZD WMP prices.

effect is significant at the 1 percent level. Exchange rates *do* respond to terms of trade shocks. Specifically, when the export price index suddenly and unexpectedly increases, the exchange rate appreciates. Figure 14 shows these results graphically in scatter plots to demonstrate that they are not driven by a single outlier event.

These movements are sizable compared with the mean daily standard deviation of the New Zealand dollar. Scaling by the mean USD/NZD exchange rate, a 0.010 percent movement corresponds to a 0.014 move in the exchange rate for a 1 percent change in the surprise component of WMP auction prices. Scaling by the mean absolute value of the surprise metric, on average we will see a roughly 0.055 move in the USD/NZD exchange rate after an auction announcement—quite a bit larger than the mean daily standard deviation of 0.0029.[26]

Columns 2 and 4 in Table 5 show that controlling for the expected change in WMP auction prices increases the magnitude of the unanticipated component slightly, to 0.012 percent and 0.011 percent for the USD and AUD exchange rates, respectively. This is because the expected change in price is negatively correlated with the surprise metric. Table 6 shows that when markets expect prices to rise by 1 percent relative to the prices from the preceding auction, prices tend to be 0.4 percent lower than expected. They still rise by 0.6 percent compared with the prices from the preceding auction, but they do not rise as much as expected.

It is somewhat surprising that the coefficient on the expected change in price in Columns (2) and (4) of Table 5 is significant. Although according to the efficient market hypothesis, exchange rates should react only 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 condition on the

[26] A similar statement applies to the AUD/NZD exchange rate. Scaling by the mean exchange rate, a 0.009 percent movement corresponds to a roughly 0.010 move in the exchange rate for a 1 percent change in the surprise component of WMP auction prices. Scaling by the mean absolute value of the surprise metric, on average we will see a roughly 0.042 move in the AUD/NZD exchange rate after an auction announcement. Compare this with the mean daily standard deviation of 0.0015.

futures prices, so they interpret any change in WMP prices as news, whether it is expected or unexpected. That said, this coefficient is not significant in single-variate regressions, as shown in Table 7.

To understand the benefits of my tight event window and provide evidence for the usefulness of a high-frequency event study in this context, I run the specifications in Columns (1) and (3) from Table 5 with event windows that gradually lengthen by 15 minutes. Figure 15 shows how standard errors become 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.

However, we can see that the point estimate drifts such that the magnitude increases with a longer event window. Although it is important not to over-interpret this result due to the rising standard errors, this is a pattern similar to that seen in the post-earnings-announcement drift literature.[27] Markets may take time to process the information from the auction, and the response within the first 15 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 wider event window may give us a better sense of the actual magnitude of the exchange rate response, while a tighter window guarantees less noise and smaller standard errors.

Although 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 0.00054 higher on auction days than non-auction days, which corresponds to 36 percent of the mean daily standard deviation (0.0015). For the USD/NZD exchange rate, it is 0.00090 higher, which corresponds to 31 percent of the mean standard deviation (0.0029).

[27]See Fink (2021) for a review.

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):

$$e_t = -\sum_{j=0}^{\infty} \mathbb{E}_t(i_{t+j} - i^*_{t+j}) - \mathbb{E}_t \sum_{j=0}^{\infty} rx_{t+j} + \lim_{j\to\infty} \mathbb{E}_t\, e_{t+j+1}, \quad (4)$$

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 rx is the log excess return of the exchange rate. This equation comes from iterating forward the standard uncovered interest 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, the terms of trade could affect the nominal exchange rate through three potential channels: (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. 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 Appendix C 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 responding only 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 the domestic CPI. If the monetary authority targets the CPI, it would respond by lowering the interest rate. In this sense, monetary policy is also an important factor in mediating the financial flow and fundamental channels.[28,29]

I first provide evidence against the direct monetary policy channel by showing that

[28]The Reserve Bank of New Zealand (RBNZ) does indeed consider all these different channels, according to conversations with RBNZ economists.

[29]Nominal exchange rate appreciations have multiple consequences for the New Zealand economy. Exchange rate appreciations adversely affect exporting firms. Those that price their goods in New Zealand dollars see their goods become less competitive, while those that price their goods in foreign currency make less profit in New Zealand dollar terms. Similarly, import-competing firms 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 RBNZ does have an inflation target band, and the RBNZ governor can be fired if the 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).

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:

$$\Delta e_a^{NZD/f} = \alpha + \beta s_a + \gamma \Delta i_{\tau,a}^{f-NZ} + \varepsilon_a. \tag{5}$$

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

The results are given in Tables 8 and 9. The USD daily result without the interest rate spread control is given in Column 1 of Table 8. The New Zealand dollar appreciates 0.010 percent against the USD for a 1 percent 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 percent, though as we would expect from the increasing standard error bars in Figure 15, the daily result is not significant. Including the interest rate spread return (Column 3) does not cause this estimate to change. Indeed, the response of the exchange rate to the interest rate is not significant. In Table 9, I use the Australian dollar exchange rate and the interest rate spread to the Australian one-year government bond. The NZD/AUD exchange rate is indeed sensitive to the interest rate spread, and the elasticity has a magnitude greater than the elasticity to WMP price shocks (though it is still smaller 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 its 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.

To distinguish between these two monetary policy response types, I replace the dependent variable in Equation 2 with the New Zealand interest rate:

$$\Delta i^{NZ}_{\tau,a} = \alpha + \beta s_a + \varepsilon_a, \tag{6}$$

where $i^{NZ}_{\tau,a}$ 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 respond only 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 one-year interest rate measure how the market anticipates the RBNZ will respond within the year.

As Table 10 shows, New Zealand interest rates do not seem to move with surprise changes to WMP prices. From a Dornbusch (1976) perspective, this would be the optimal policy if the price shocks were permanent. However, as the model in the appendix shows, this is potentially puzzling if we consider a temporary shock and a monetary authority that targets CPI inflation.[30]

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.[31] 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 follow a GDT auction. Whole milk powder is denominated and traded in US dollars, meaning that Fonterra bears the currency risk of the auction. When USD prices are higher than expected, Fonterra is paid a greater number of US dollars, which it then exchanges for New Zealand dollars. If financiers need to mediate this exchange, and if they are limited in their risk-bearing capacity, they will 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.[32] In this

[30]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. 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, it may act to keep interest rates from rising. This corresponds to the second monetary policy pathway, whereby 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 coefficient magnitudes in my baseline regression that are smaller than if the shock were permanent and monetary policy were nonreactive.

[31]There 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).

[32]Fonterra 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 from what is expected when the hedge was entered into, Fonterra will need to either buy or sell the New Zealand dollar in order to fully convert its

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.[33]

In Appendix B, 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 are 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.[34] Unfortunately both are weak tests in that significant results would provide evidence of 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.

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 and estimate the elasticity of the nominal exchange rate to the surprise *quantity* of financial flows, and I compare this elasticity estimate to results in the existing literature. In my high-frequency estimates, I find that a 1 percent WMP price surprise corresponds to a 0.01 percent nominal exchange rate appreciation. This 1 percent 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

receipts.

[33]For others, see Hau, Massa and Peress (2010), Pandolfi and Williams (2019), and Broner et al. (2020).

[34]Specifically, CIP fails in the Gabaix 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.

revenue of WMP sold at the auction gives a lower bound for this estimate and averages 59 million USD. Total annual New Zealand WMP exports divided by the number of auctions in a year gives an upper bound and averages 188 million USD. A fair middle ground could be established by taking this upper bound and multiplying 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, implying that a 1.66 million USD flow leads to a 1 percent nominal exchange rate movement. The average annual New Zealand GDP from 2010 through 2019 was 187,855 million USD. This means that a 1 percent surprise inflow as a percentage of GDP leads to an 11 percent appreciation.[35] In contrast, Broner et al. (2020) find that a 1 percent inflow as a percentage of GDP leads to a 0.9 percent 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, there is probably an additional mechanism at play.

5.3 Fundamental Channel

Finally, I turn to the last channel, which may be called the "fundamental channel." Under this channel, an increase in the price of dairy from an external demand shock causes an increase in prices across production sectors in the domestic economy. Conceptually, this can arise due to either 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 real exchange rate appreciates, and under sticky prices, the nominal exchange rate appreciates as well.[36] This nominal exchange rate appreciation

[35] With my lower bound of the financial flow size, this number rises to 32 percent. With my upper bound, the number falls to 10 percent.

[36] This is the channel that is operative when a foreign demand shock appears in an open-economy New Keynesian model (for example, Galí and Monacelli, 2005), and it is also described in Chen and Rogoff (2003). Specifically, Chen and Rogoff (2003) describes a model where the import good is the numeraire, and the price of the non-traded good adjusts via mobile labor such that the impact of the rise in the price of the export good is similar to a rise in traded good productivity in the standard Belassa-Samuelson model. Under sticky non-traded prices, optimal monetary policy would seek to replicate the flexible price equilibrium, implying that the exchange rate should adjust 1-for-1 with changes in the export good price. If the monetary

can be persistent even if the initial external demand shock is temporary. Appendix C demonstrates this result using impulse responses based on a model of this mechanism.

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 appreciations should be entirely absorbed by nominal exchange rate appreciations, without a change in the price level or the interest rate.[37] As Figure 16 shows, however, WMP price shocks seem to be temporary, and prices mean-reverted over the course of roughly a year during this period.[38] This mean-reversion is a documented feature of agriculture commodity prices (Peterson, Ma and Ritchey, 1992; Bessembinder et al., 1995; Wang and Tomek, 2007).[39]

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 respond to the inflation effect of nominal exchange rate appreciation. Specifically, currency appreciation reduces inflation, so an inflation-targeting monetary authority should lower the interest rate in response. This makes the lack of interest rate response to WMP price surprises somewhat puzzling.[40] This could be reconciled if the market-based interest rate does not

authority seeks to stabilize CPI inflation, it would not allow the nominal exchange rate to move by the full amount required.

[37]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.

[38]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 involved supply: a 2013 drought and the strong supply response. The structural factors involved Chinese growth as well as a changing milk market in China as part of the 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.

[39]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.

[40]The model in Appendix C also illustrates a case where the exchange 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

seem to respond due to short-term illiquidity and long-term noise, though one must be careful in making claims outside of the data.

Regardless of the monetary policy response, however, 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 alone, implying that this fundamental channel is likely in effect.

6 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 advance our understanding of exchange rate determination. Seeking out additional natural experiments may be a fruitful avenue for future research.

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applicable to a more complex world.

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	NZD/USD	NZD/AUD
Mean	1.353	1.138
Std. dev	0.123	0.097
Mean daily std. dev	0.0029	0.0015
Min	1.132	1.002
Max	1.612	1.379

Table 1: **Summary statistics for the New Zealand dollar.** Summary statistics are reported for the sample period October 8, 2010, through December 31, 2019, and are calculated using minute-by-minute data on trading days during the sample period. Mean daily standard deviation is calculated by averaging the standard deviation on each trading day during the sample period. Minute-by-minute exchange rate data are sourced from histdata.com.

Observations	217
Mean	-0.010
95% CI of mean	[-0.018, -0.002]
Std. dev.	0.057
Min	-0.192
Max	0.330
Mean of absolute value	0.041

Table 2: **Summary statistics for the surprise metric.** The surprise metric is calculated per Equation 3 using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange.

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

Table 3: **Summary statistics for amount of WMP sold to each region.** This table gives amount of whole milk powder (WMP) sold, in metric tons (MT) and percentile terms, to each region from October 2010 through December 2019. Data come from the Global Dairy Trade Historic Market Pack.

	Cumulative abnormal log change						
	(1) USD/AUD	(2) HKD/USD	(3) JPY/USD	(4) SGD/USD	(5) WTI	(6) Silver	(7) Gold
Surprise Δ WMP	0.0003	−0.0000	−0.0008	0.0004	0.0015	−0.0012	0.0011
	(0.0015)	(0.0001)	(0.0012)	(0.0007)	(0.0055)	(0.0042)	(0.0025)
Constant	−0.0000	0.0000	−0.0000	0.0001*	−0.0005	−0.0001	0.0001
	(0.0001)	(0.0000)	(0.0001)	(0.0000)	(0.0003)	(0.0002)	(0.0001)
Observations	212	212	212	212	212	212	212
R2	0.000	0.000	0.002	0.001	0.000	0.000	0.001

Table 4: **The impact of surprise WMP price changes on various currencies and commodities within 15 minutes after the announcement.** This table reports the results of placebo tests in which I replace the the New Zealand exchange rate in Equation 2 with other exchange rates and with commodity prices. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise metric is calculated per Equation 3 using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Minute-by-minute exchange rate and commodity price data are sourced from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
Surprise Δ WMP	−0.010***	−0.012***	−0.009***	−0.011***
	(0.002)	(0.002)	(0.001)	(0.002)
Expected Δ WMP		−0.004*		−0.005***
		(0.002)		(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	212	209	212	209
R2	0.090	0.104	0.167	0.183

Table 5: **The impact of surprise WMP price changes on the New Zealand dollar within 15 minutes after the announcement.** Columns (1) and (3) report the results of the baseline specification in Equation 2. Columns (2) and (4) control for the expected change in whole milk powder (WMP) auction prices. The cumulative abnormal exchange rate is calculated using an event window of 5 minutes before the announcement time through 15 minutes after the announcement time and an estimation window of 60 before the announcement time through 5 minutes before the announcement time. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise and expected WMP price changes are calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Minute-by-minute exchange rate data are sourced from histdata.com. Auction announcement times were collected from Bloomberg.

	(1) Surprise Δ WMP	(2) Total Δ WMP
Expected Δ WMP	−0.409***	0.591***
	(0.062)	(0.062)
Constant	−0.005	−0.005
	(0.004)	(0.004)
Observations	209	209
R2	0.174	0.306

Table 6: **Correlation between the expected and unanticipated components of WMP price changes.** Column (1) reports the results of regressing the surprise change in whole milk powder (WMP) prices on the expected change in WMP prices. Column (2) reports the results of regressing the total change in WMP prices on the expected change in WMP prices. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise and expected WMP price changes are calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange.

	Cumulative abnormal Δe	
	(1) NZD/USD	(2) NZD/AUD
Expected Δ WMP	0.000	−0.000
	(0.002)	(0.002)
Constant	0.000	0.000*
	(0.000)	(0.000)
Observations	209	209
R2	0.000	0.000

Table 7: **The impact of expected WMP price changes on the New Zealand dollar within 15 minutes after the announcement.** This table reports the results of regressing the cumulative abnormal change in the exchange rate on the expected change in whole mile powder (WMP) prices. The cumulative abnormal exchange rate is calculated using an event window of 5 minutes before the announcement time through 15 minutes after the announcement time and an estimation window of 60 before the announcement time through 5 minutes before the announcement time. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The expected WMP price changes is calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Minute-by-minute exchange rate data are sourced from histdata.com. Auction announcement times were collected from Bloomberg.

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

Table 8: **The daily impact of surprise WMP price changes on the NZD/USD exchange rate, controlling for interest rate spreads.** This table reports the results of Equation 5 for the NZD/USD exchange rate using the interest rate spread between one-year United States government bonds and one-year New Zealand government bonds. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise and expected WMP price changes are calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Daily interest rate data are sourced from Bloomberg, and exchange rate data are sourced from histdata.com. Minute-by-minute exchange rates are compressed to the daily frequency by taking the exchange rate at 10pm Greenwich Mean Time (GMT).

	Δe			
	(1) NZD/AUD	(2) NZD/AUD	(3) NZD/AUD	(4) NZD/AUD
Surprise Δ WMP	−0.011**		−0.010*	−0.013**
	(0.005)		(0.005)	(0.006)
Δi_{1y}^{AU-NZ}		0.054***	0.052***	0.053***
		(0.018)	(0.017)	(0.017)
Expected Δ WMP				−0.006
				(0.005)
Constant	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	217	212	212	211
R2	0.020	0.043	0.059	0.066

Table 9: **The daily impact of surprise WMP price changes on the NZD/AUD exchange rate, controlling for interest rate spreads.** This table reports the results of Equation 5 for the NZD/AUD exchange rate using the interest rate spread between one-year Australian government bonds and one-year New Zealand government bonds. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise and expected WMP price changes are calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Daily interest rate data are sourced from Bloomberg, and exchange rate data are sourced from histdata.com. Minute-by-minute exchange rates are compressed to the daily frequency by taking the exchange rate at 10pm Greenwich Mean Time (GMT).

	Δi_{τ}^{NZ}		
	(1)	(2)	(3)
	3M	1Y	2Y
Surprise Δ WMP	0.005	0.003	0.002
	(0.014)	(0.013)	(0.016)
Constant	−0.000	−0.000	0.001
	(0.001)	(0.001)	(0.001)
Observations	212	212	212
R2	0.001	0.000	0.000

Table 10: **The daily impact of surprise WMP price changes on New Zealand government bond yields of different tenors.** This table reports the results of Equation 6 using New Zealand government bond yields of various tenors. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The surprise WMP price changes are calculated using auction price data from Global Dairy Trade and futures data from New Zealand's Exchange. Daily interest rate data are sourced from Bloomberg.

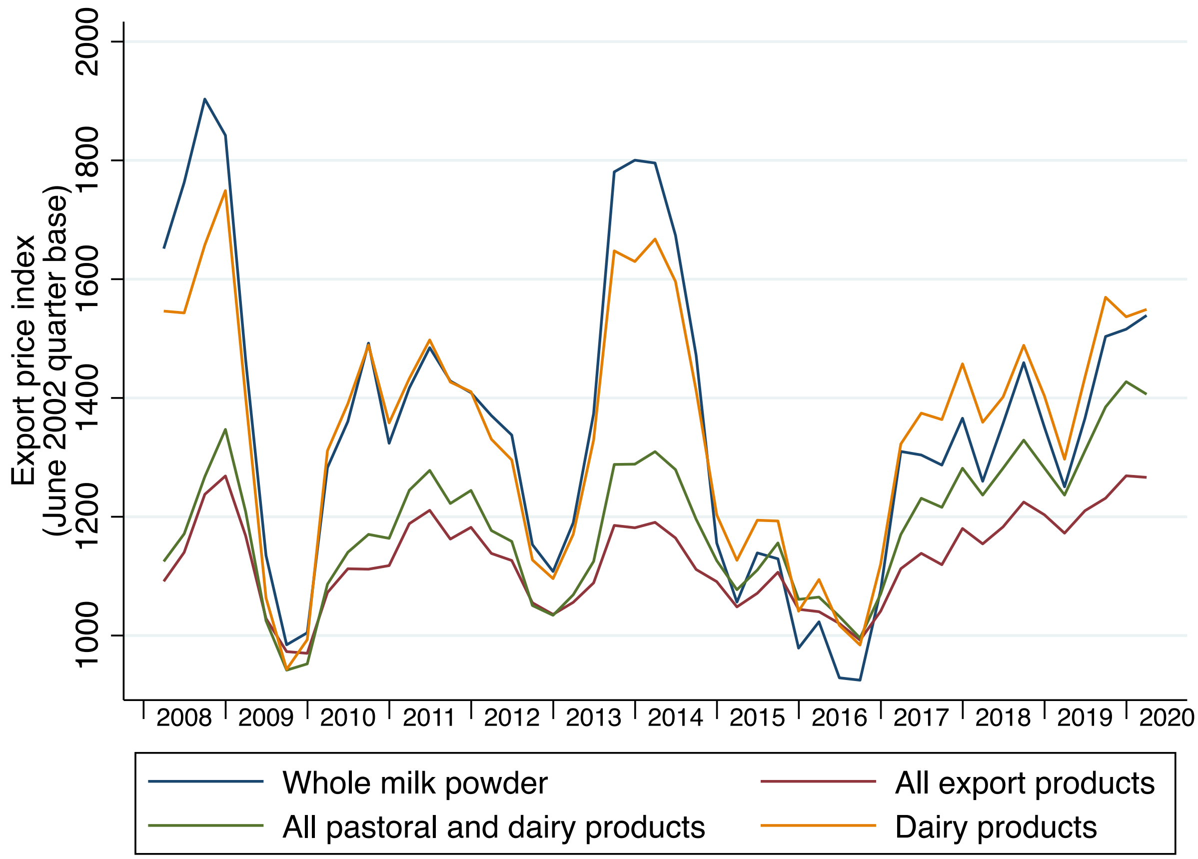


Figure 1: **New Zealand export price indices.** This figure shows the time series of various export price indices, as reported by Statistics New Zealand in its Overseas Trade Indexes series. The correlation between the whole milk powder price index and the overall export index is 0.77.

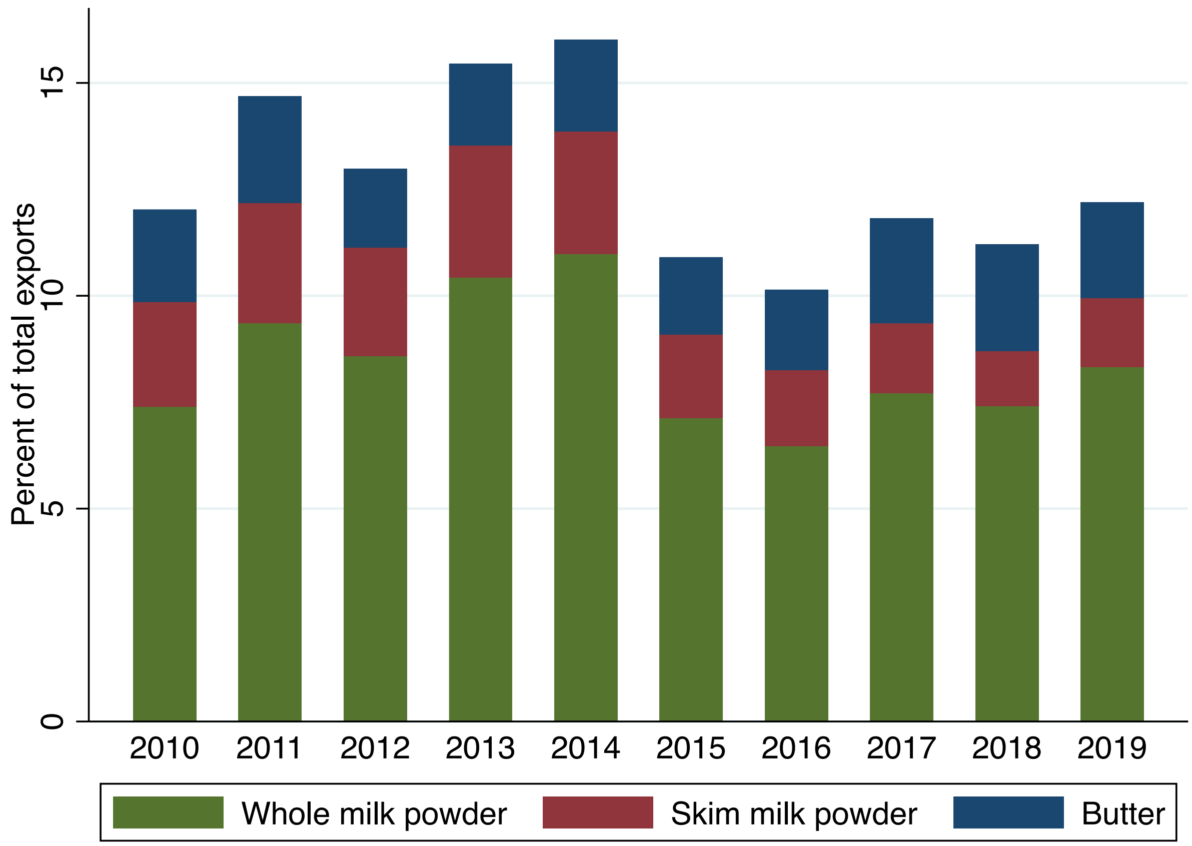


Figure 2: **Top GDT products as a percentage of exports over time.** This figure helps illustrate the importance of Global Dairy Trade (GDT) auction products in the New Zealand export basket. Whole milk powder (WMP), skim milk powder (SMP), and butter are the first-, second-, and fourth-largest items traded in the GDT auctions. Anhydrous milk fat (AMF) is the third-largest item, but export data for AMF are incorporated into a category with other goods. The export values of these products are shown as a percentage of total goods and services exports. The data behind these figures come from the UN Comtrade database and the IMF Direction of Trade Statistics databases.

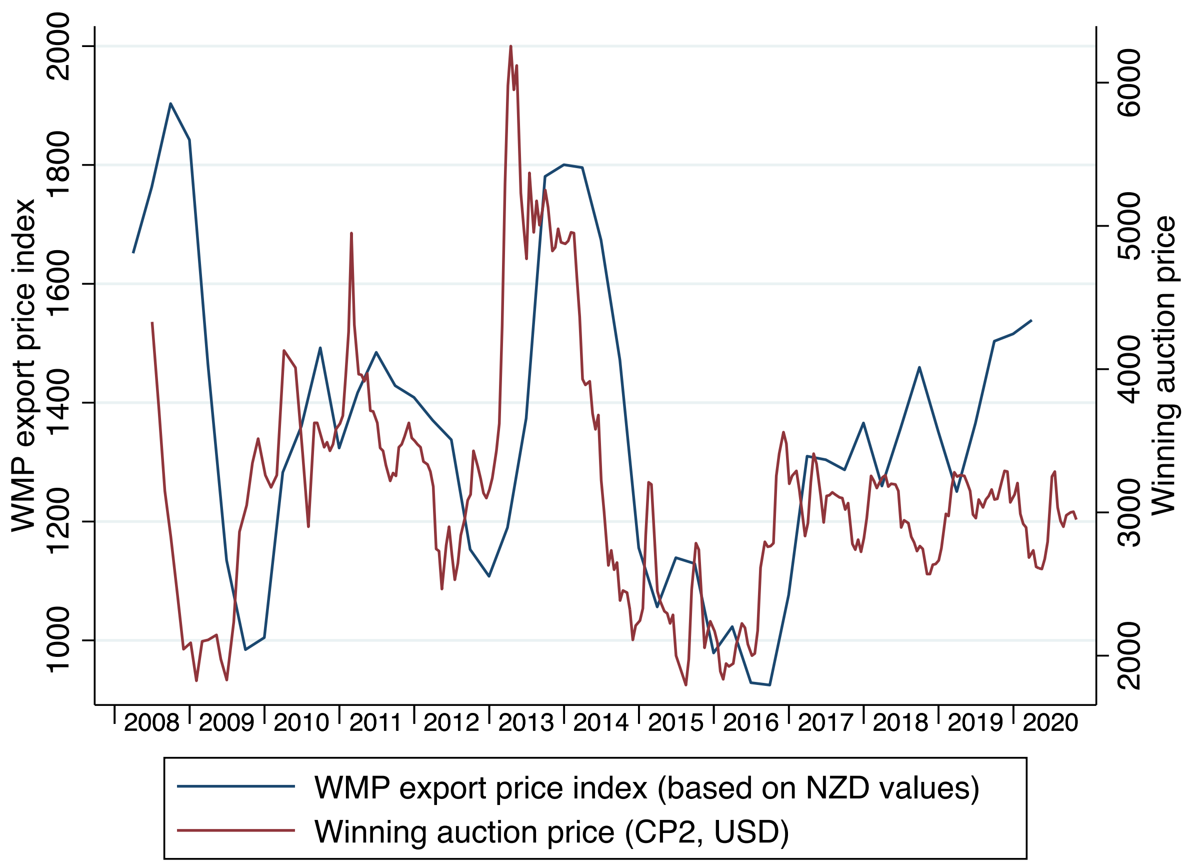


Figure 3: **Whole milk powder: auction price vs. export price index.** This figure shows how the price of whole milk powder (WMP) sold in the Global Dairy Trade (GDT) auctions is highly predictive of the WMP export price index published by Statistics New Zealand in its Overseas Trade Indexes series. The auction price shown is the price of the largest contract specification sold in the GDT auctions (CP2, regular, produced in New Zealand) and is sourced from the Global Dairy Trade Historic Market Pack.

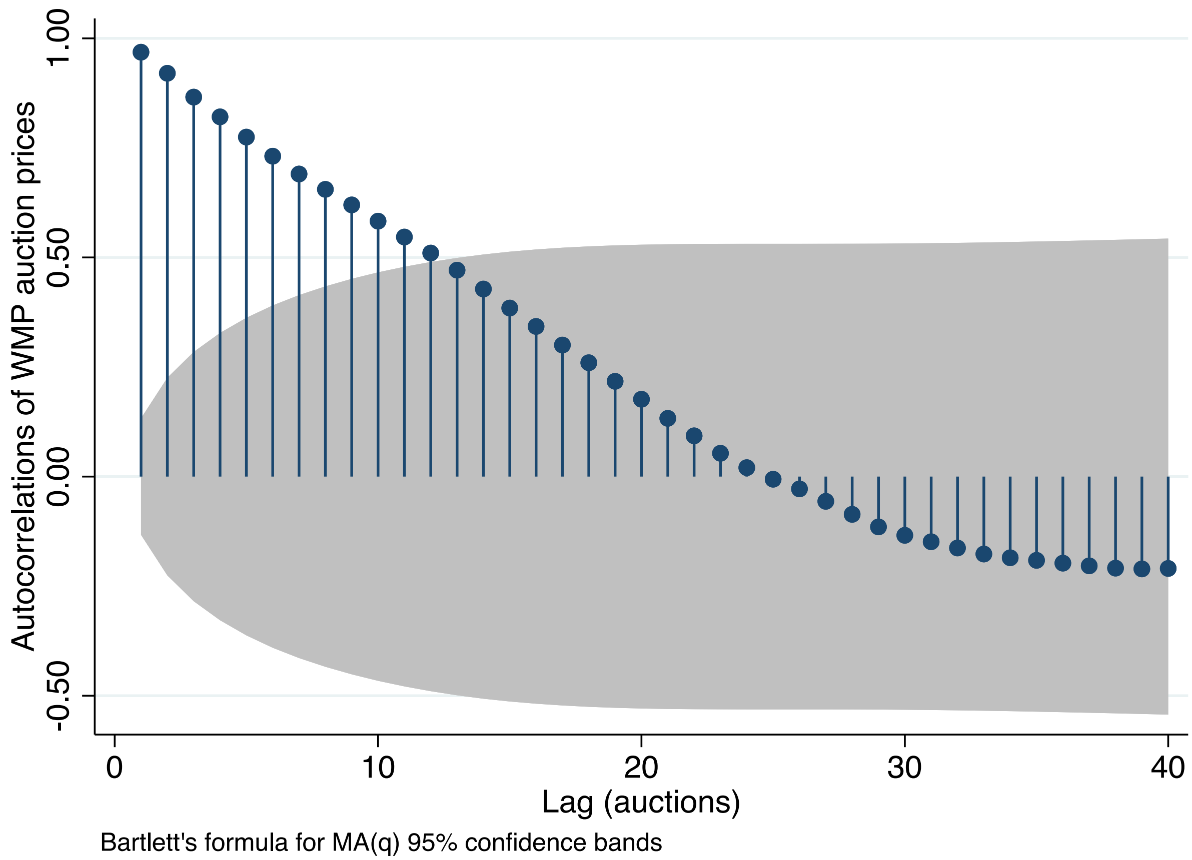
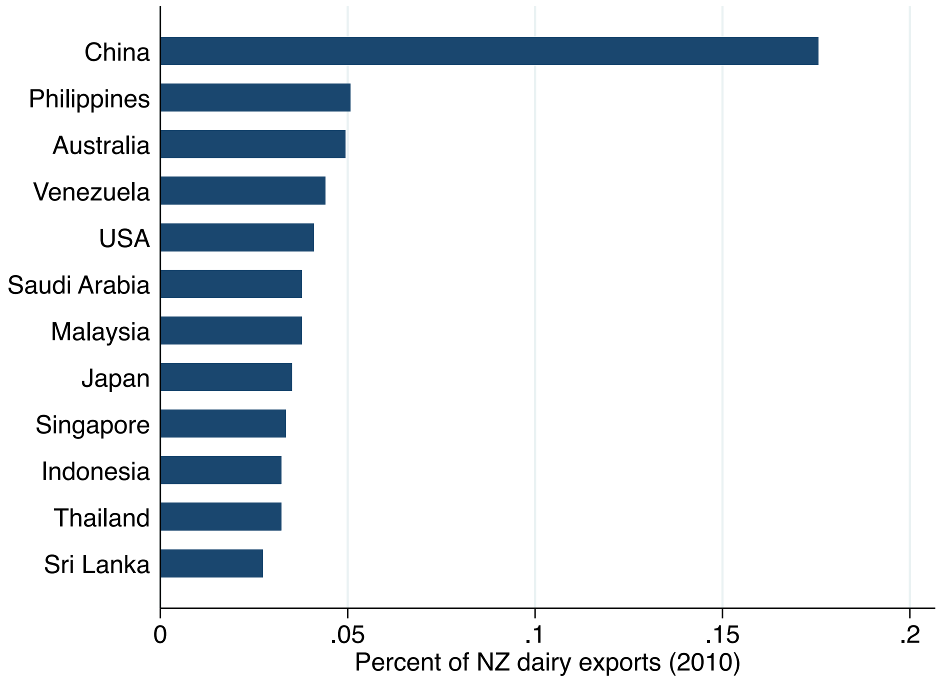
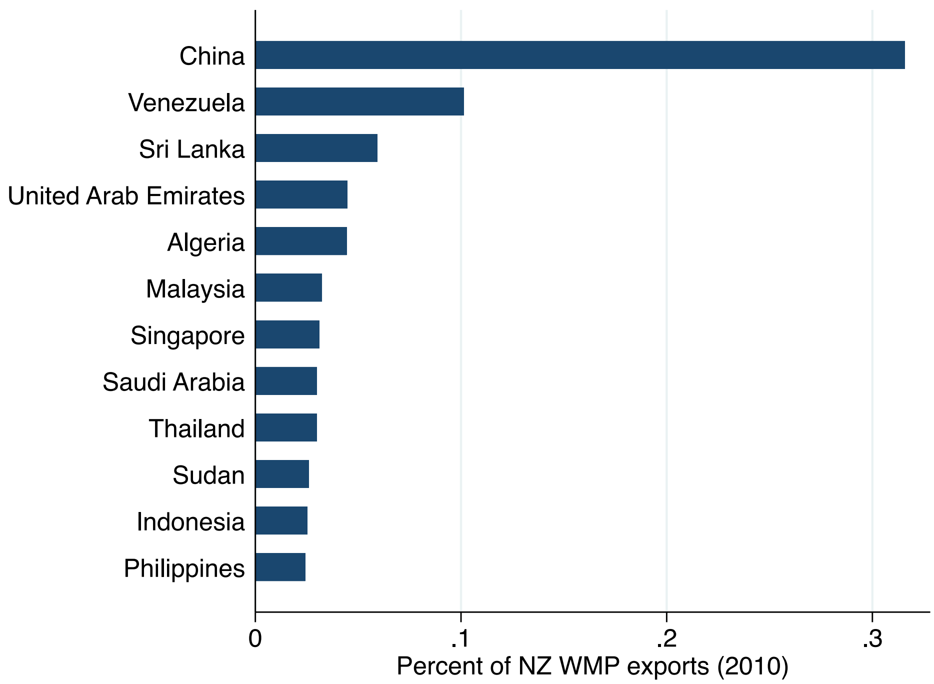


Figure 4: **Autocorrelation of WMP auction prices.** This figure shows how whole milk powder (WMP) auction prices exhibit a high degree of autocorrelation between auctions. The data are sourced from the Global Dairy Trade Historic Market Pack.



(a) All dairy



(b) WMP

Figure 5: **Top importers of New Zealand dairy.** The data behind this figure are sourced from UN Comtrade.

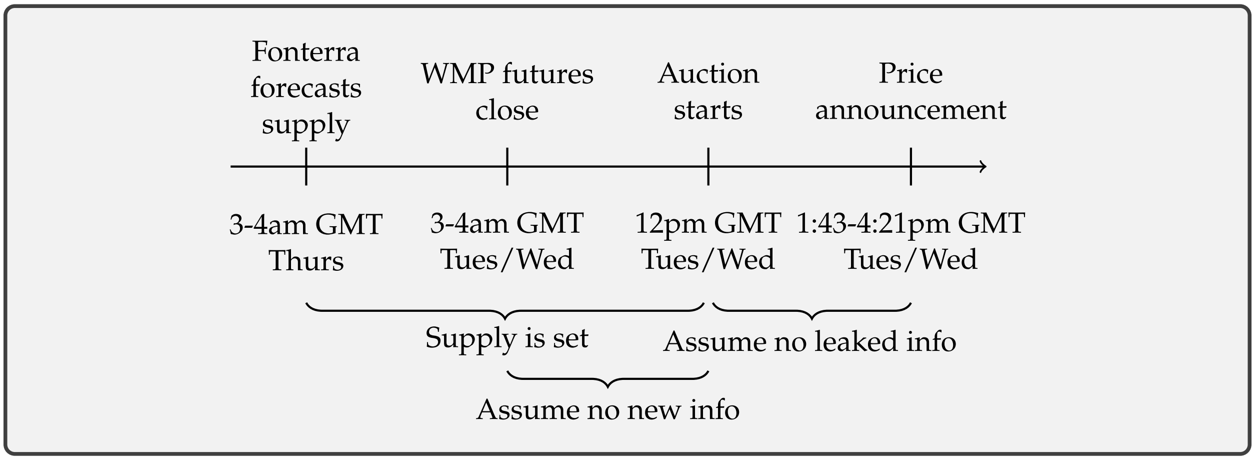


Figure 6: **Assumptions due to timing gaps.** This figure illustrates the Global Dairy Trade (GDT) auction timeline. Announcement times were collected from Bloomberg.

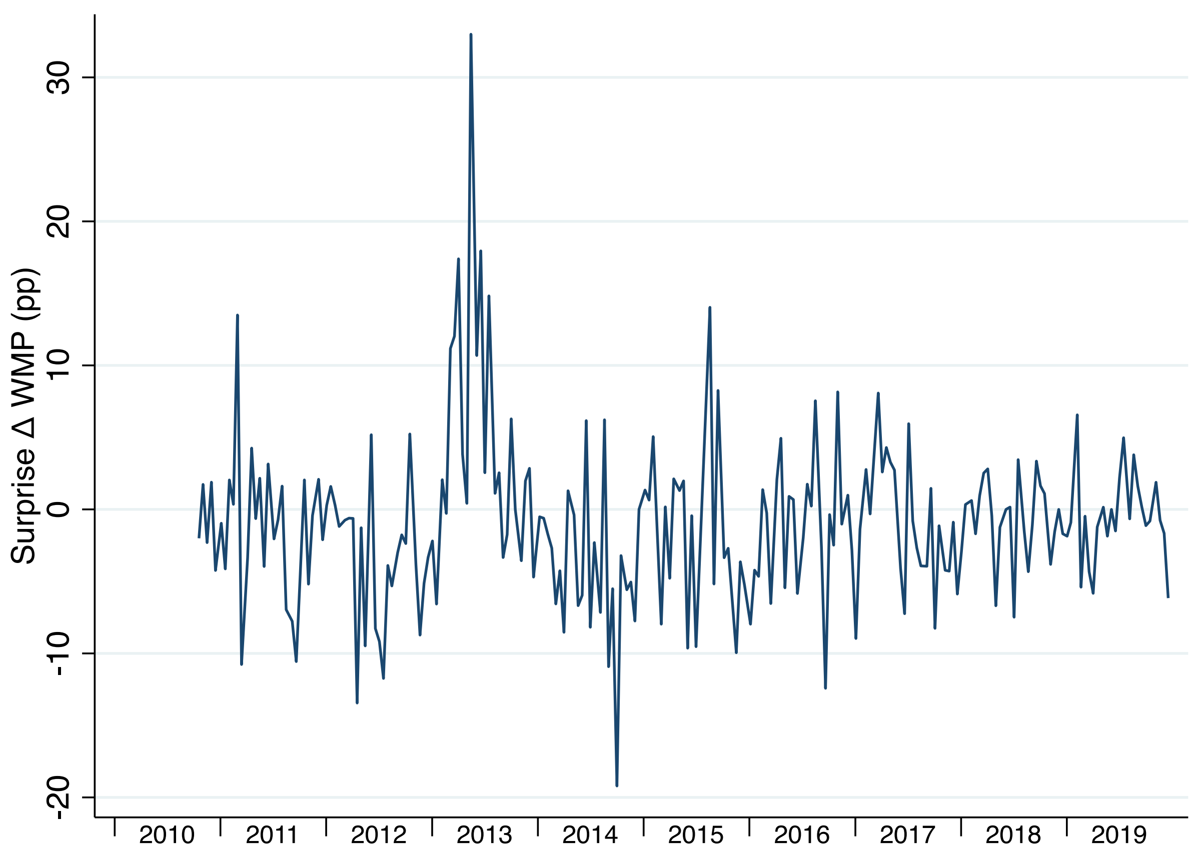


Figure 7: **Surprise metric over time.** The surprise metric is calculated per Equation 3 using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX).

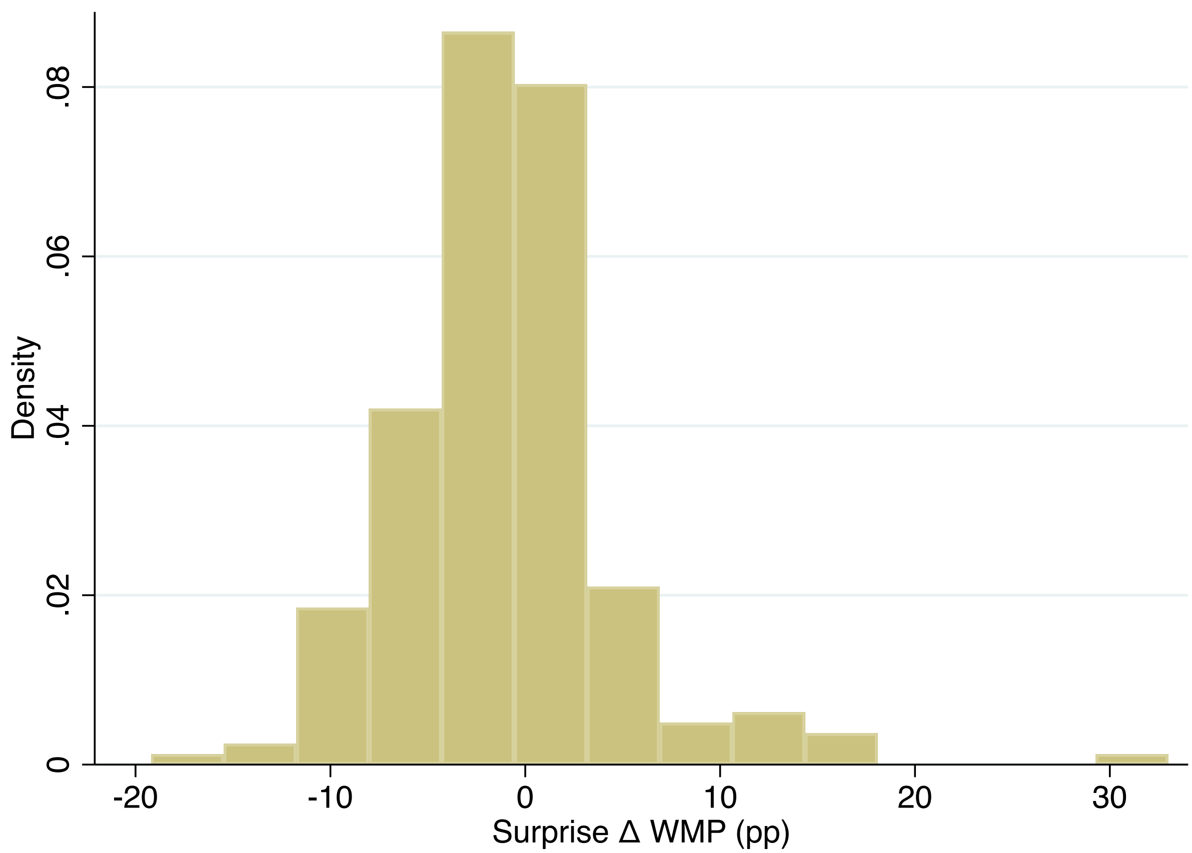


Figure 8: **Distribution of surprise metric.** The surprise metric is calculated per Equation 3 using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX).

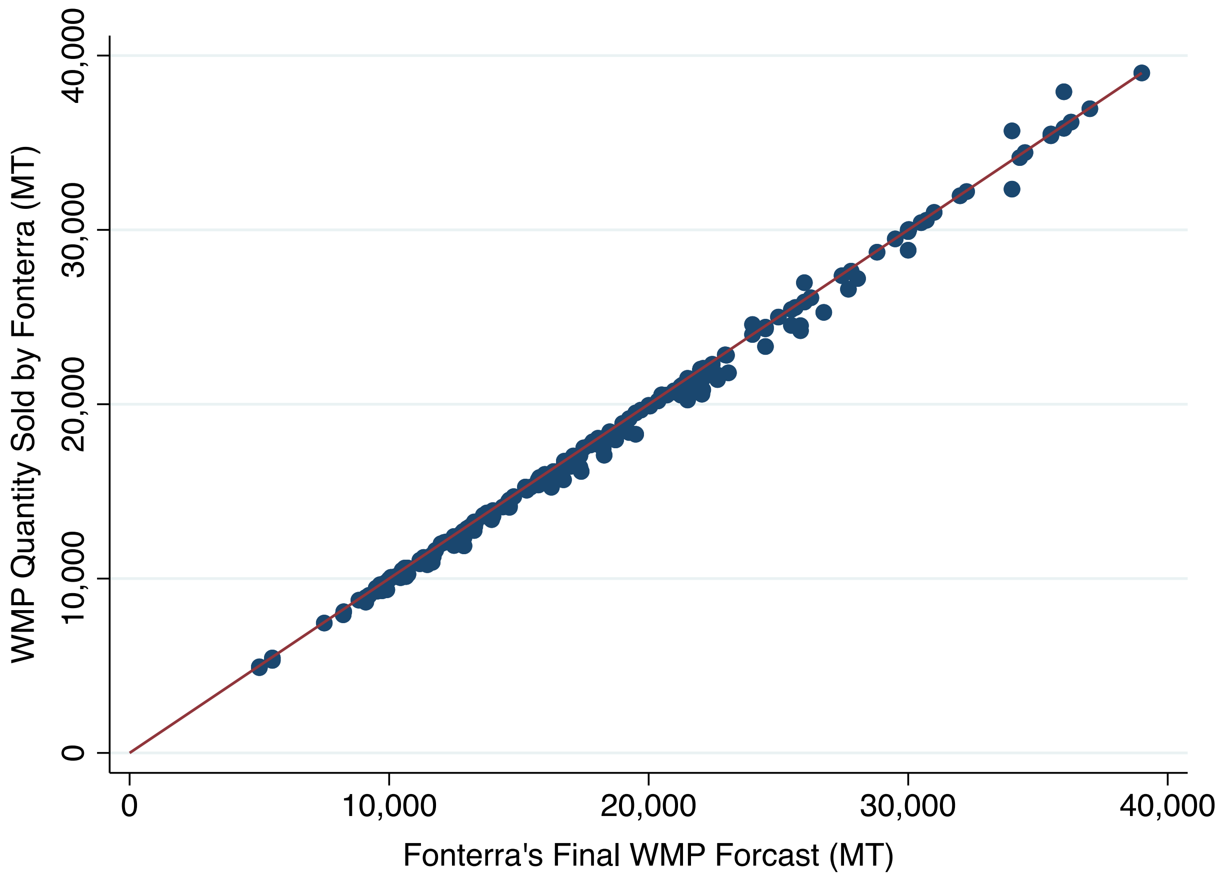
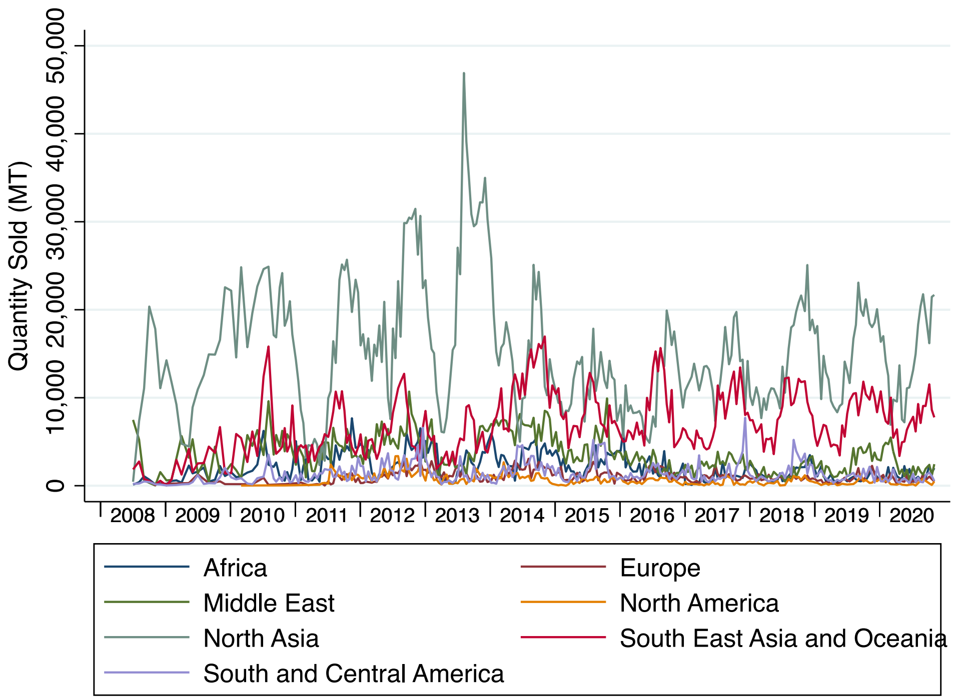
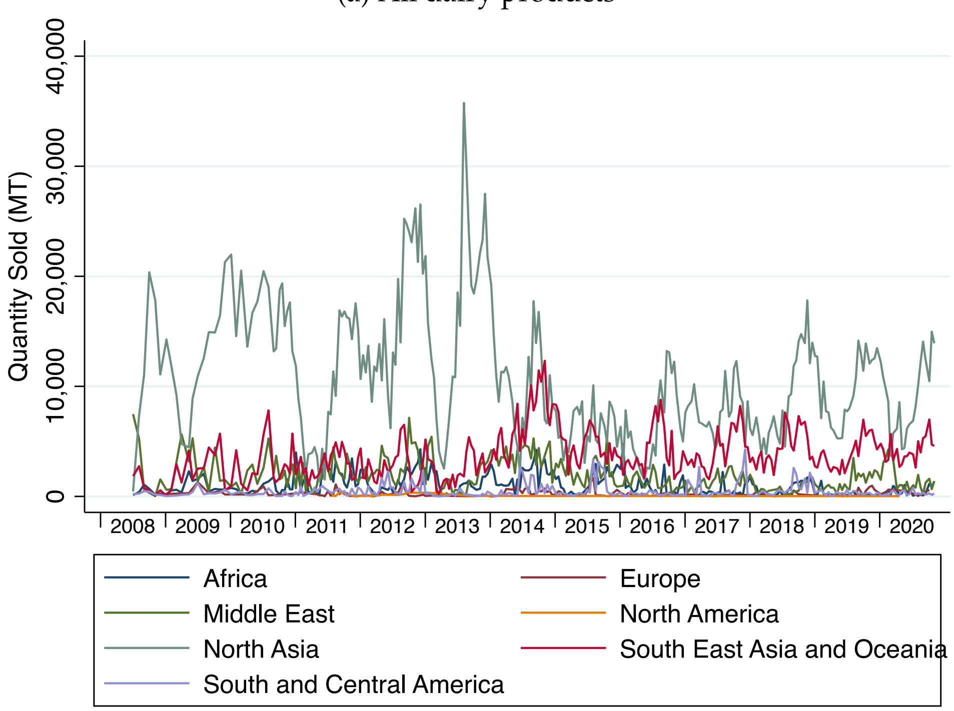


Figure 9: **Fonterra's final supply forecast for the upcoming auction.** This figure shows the accuracy of Fonterra's final auction supply forecasts. Quantities refer to the total amount across all contract periods. The red line is the 45 degree line. The first auction date graphed is October 18, 2011, due to data availability of Fonterra forecasts. These forecasts are published by New Zealand's Exchange (NZX), while the data for the actual supply are sourced from the Global Dairy Trade Historic Market Pack.



(a) All dairy products



(b) WMP

Figure 10: **Regional demand in GDT auctions.** This figure shows how north Asia, which includes China, accounts for the majority of demand in the Global Dairy Trade (GDT) auctions. Data are sourced from the Global Dairy Trade Historic Market Pack.

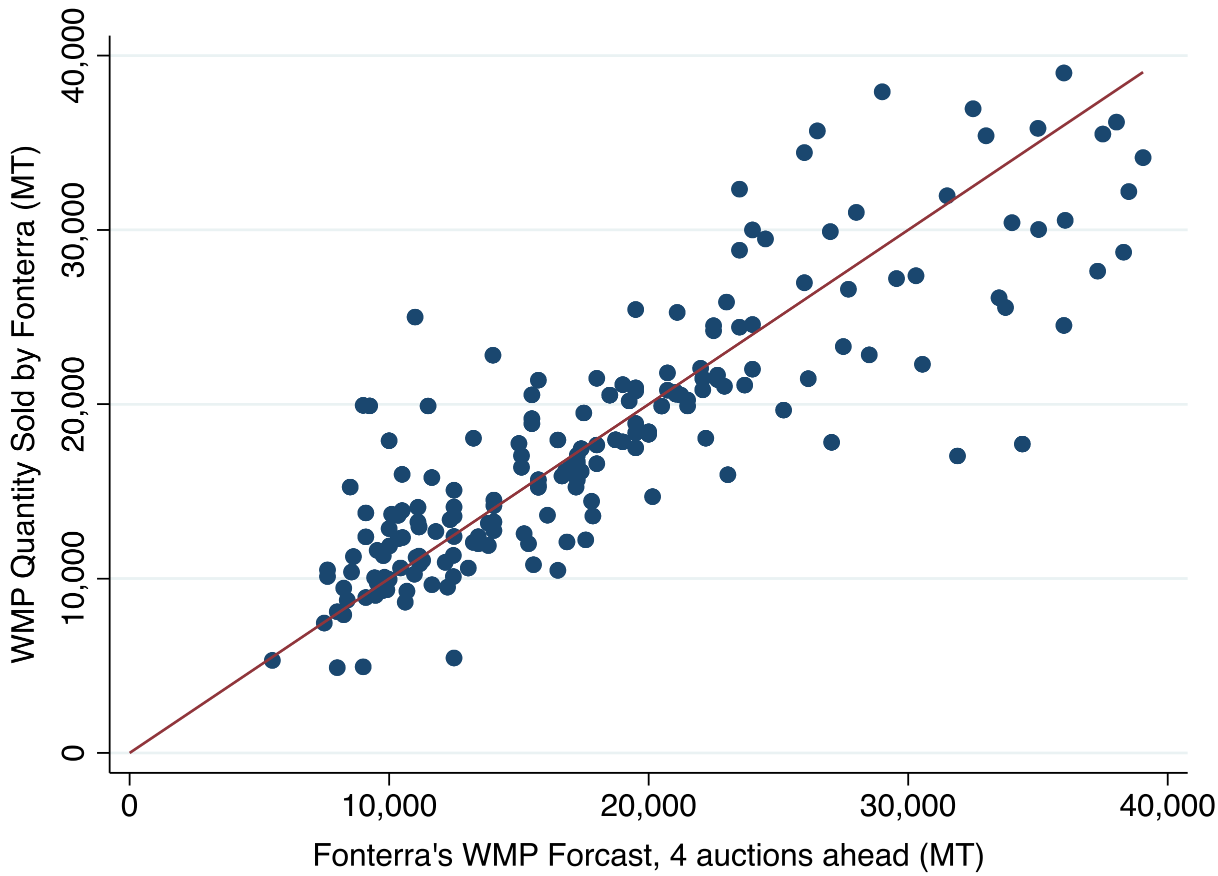
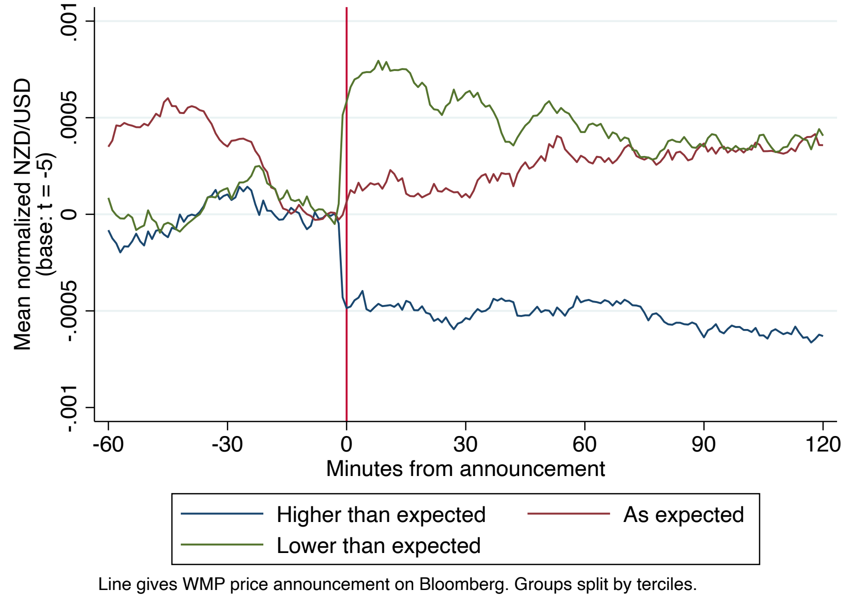
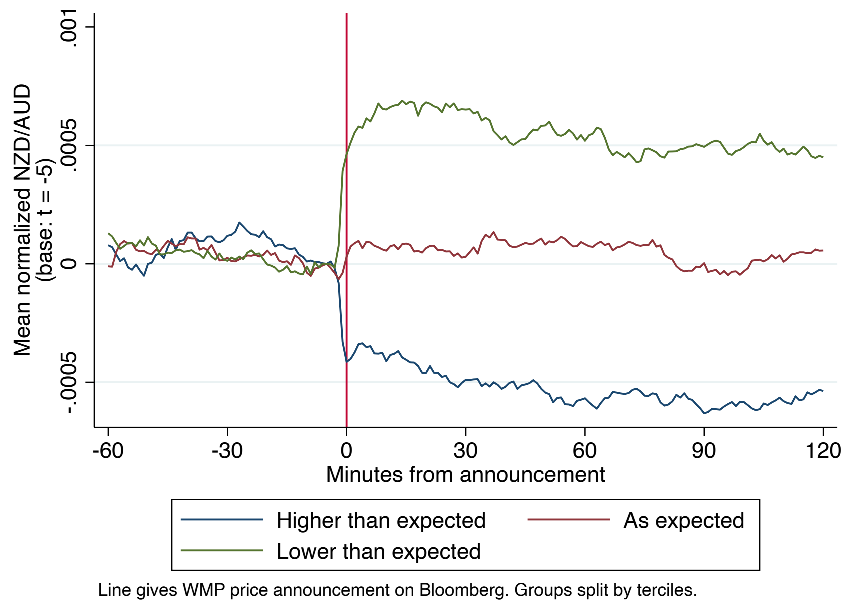


Figure 11: **Fonterra's supply forecast for the auction four auctions after the upcoming one.** Quantities refer to the total amount across all contract periods. The red line is the 45 degree line. These forecasts are published by New Zealand's Exchange (NZX), while the data for the actual supply are sourced from the Global Dairy Trade Historic Market Pack.



(a) USD/NZD



(b) AUD/NZD

Figure 12: **Mean exchange rate changes by surprise group tercile.** This figure shows that on auction days with negative whole milk powder (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. Auction dates are split into terciles based on the surprise metric for the auction that day. Minute-by-minute exchange rate data come from histdata.com. The surprise metric is calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX).

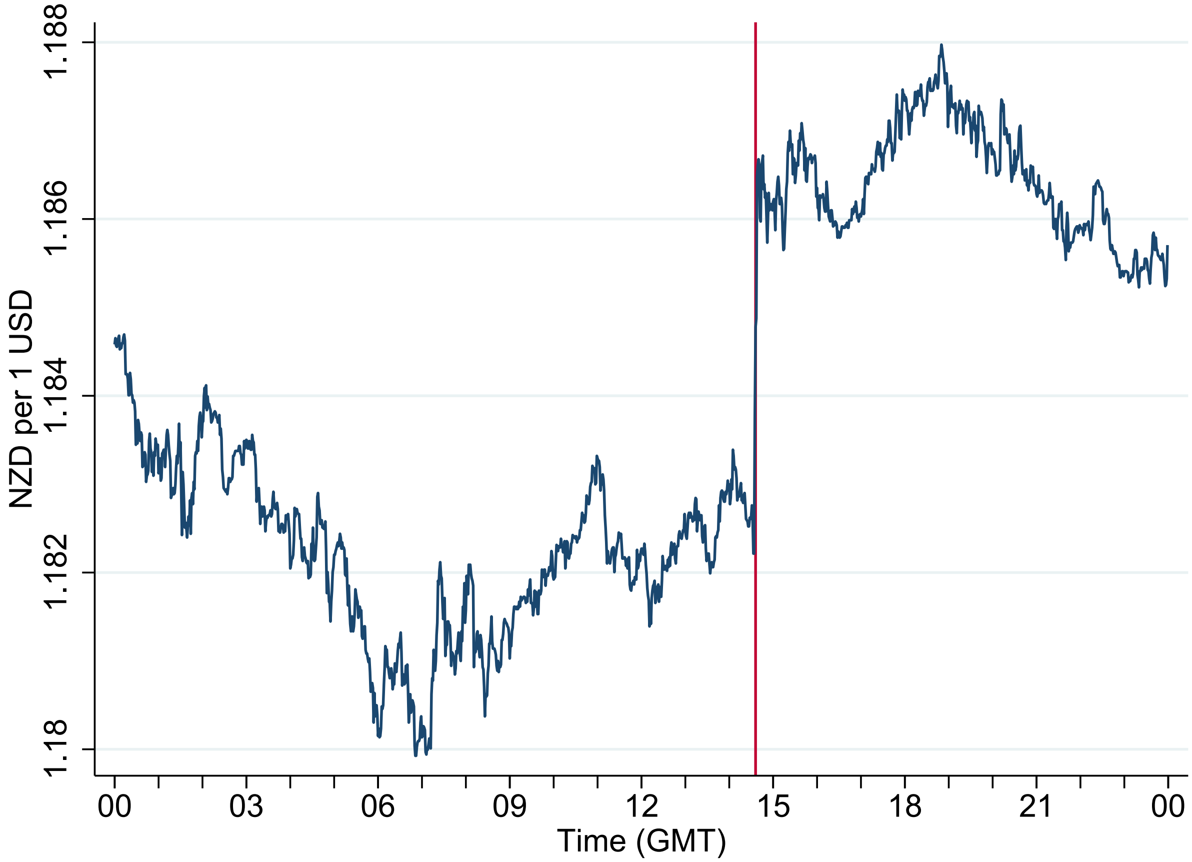
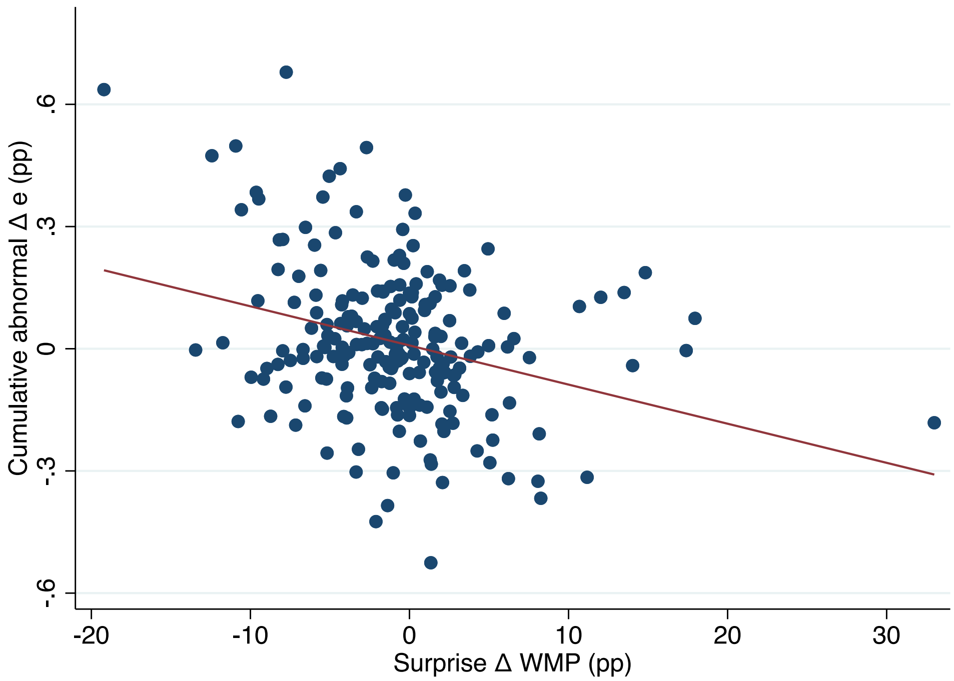
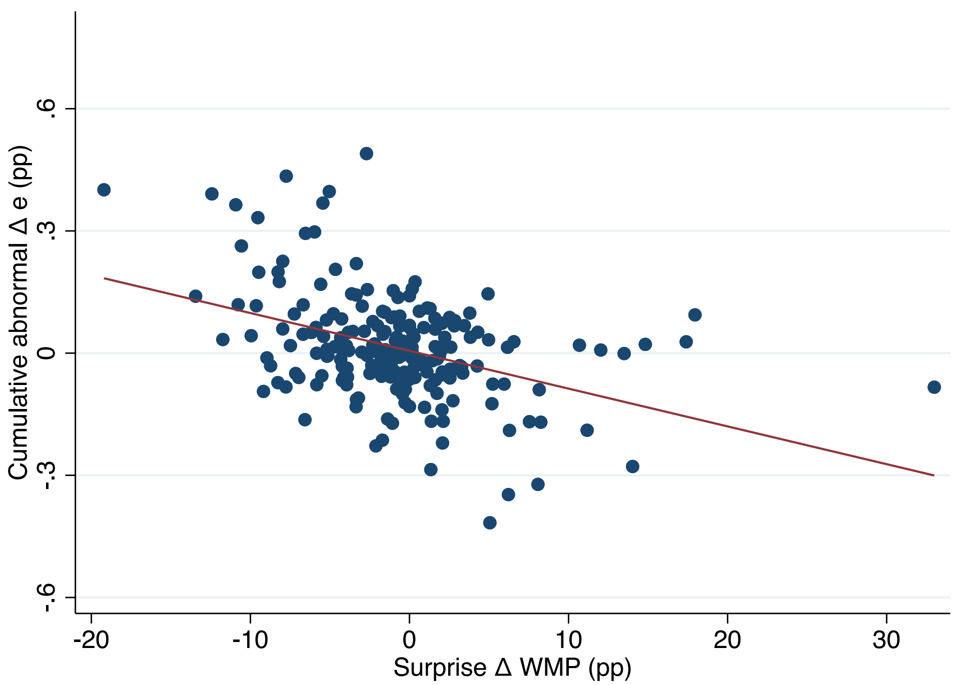


Figure 13: **Example of exchange rate response.** This figure shows how the New Zealand dollar reacted immediately after the whole milk powder (WMP) price was announced on June 3, 2014. The announcement occurred at 14:36 GMT, denoted by the vertical red line. For this particular auction, the WMP price was 10 percent less than expected. Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

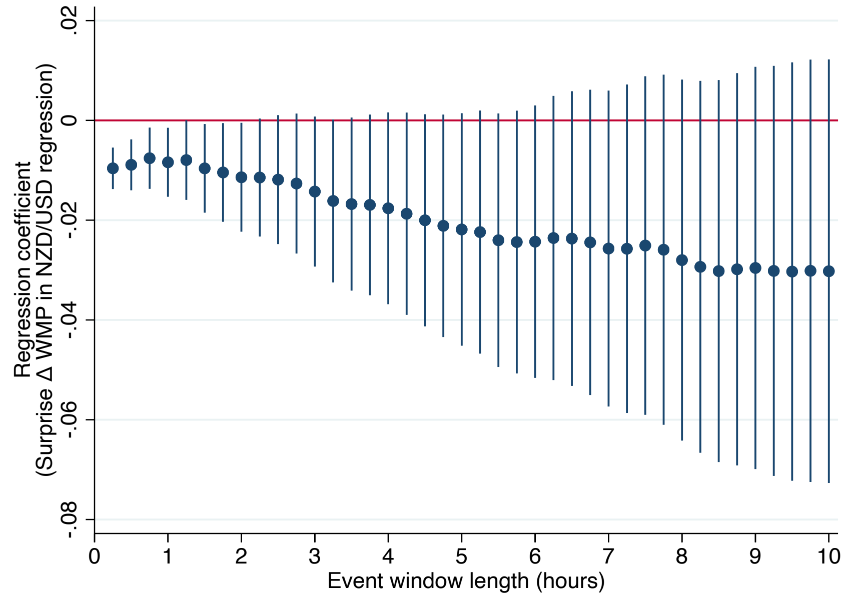


(a) USD/NZD

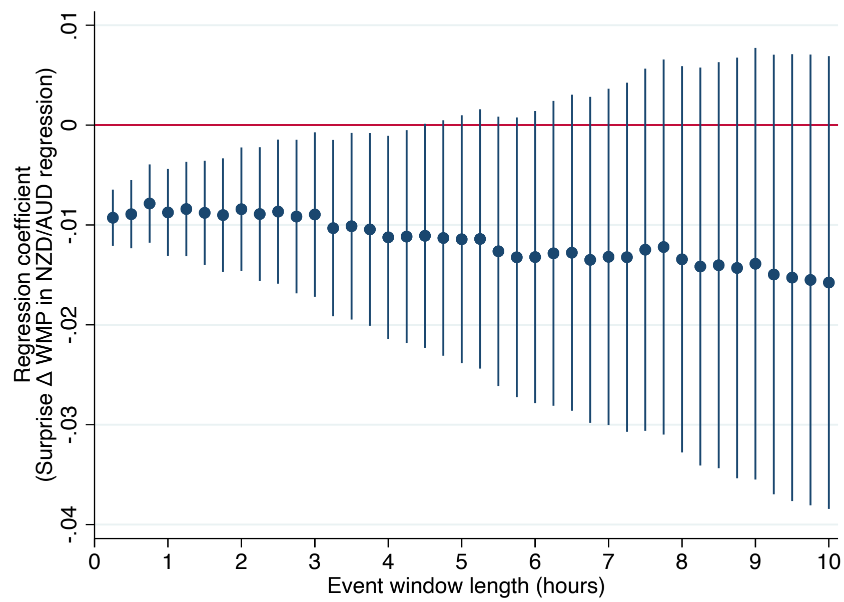


(b) AUD/NZD

Figure 14: **Correlation between surprise WMP price changes and NZD exchange rate returns within 15 minutes after auction annoucements.** This figure shows the graphical results of the baseline specification in Equation 2. Minute-by-minute exchange rate data come from histdata.com. The surprise metric is calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Auction announcement times were collected from Bloomberg.



(a) USD/NZD



(b) AUD/NZD

Figure 15: **The effect of surprise increases in WMP prices on the NZD exchange rate with a lengthening event window.** This figure shows the results of the baseline specification in Equation 2 with event windows that gradually lengthen by 15 minutes. Bars denote 95 percent confidence intervals. It is apparent that standard errors become increasingly larger as the event window lengthens. Minute-by-minute exchange rate data come from histdata.com. The surprise metric is calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Auction announcement times were collected from Bloomberg.

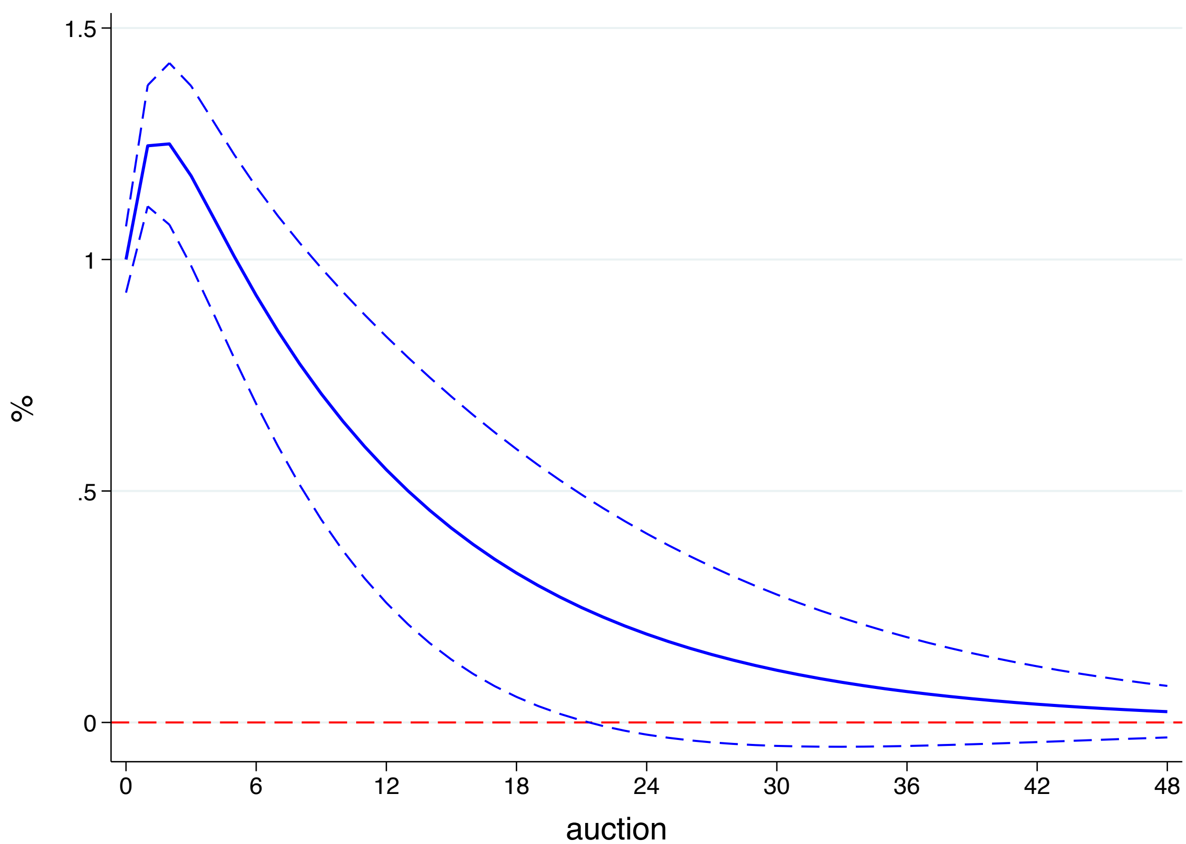


Figure 16: **VAR of log WMP auction prices, with two lags.** This figure shows how whole milk powder (WMP) price shocks seem to be temporary, with prices mean-reverting over the course of roughly a year during the sample period. Auction price data come from Global Dairy Trade (GDT).

Appendix

A Robustness Checks

My baseline specification for the elasticity of the exchange rate to surprise changes in whole milk powder (WMP) prices is given in Table 5. Here, I show a few modifications to my preferred specification. Estimates are notably 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 A.1. 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 A.2 shows that results remain significant at the 5 percent level.

Third, I take a subsample of the data, considering only dates before the Global Dairy Trade 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 toward zero. However, Table A.3 shows that the estimates from the earlier subsample are almost identical to the entire subsample, differing by only 0.001.

One way to handle the possibility of information leakage during the auction would be to expand the event window to include the duration of the auction. However, because wider event windows are subject to increased noise, the effect of interest can no longer be precisely estimated once the event window widens beyond a certain extent. Figure A.1 shows how including more time before the announcement in the event window does not change the estimate up to about two hours before the announcement. After that, the estimate becomes very noisy. Note that the length of time between the start of the auction and the announcement varies from 1 hour 43 minutes to 4 hours 21 minutes. When I consider an event window that spans the entirety of the auction from beginning to announcement, the coefficients fall in magnitude and lose significance (Table A.4).

Fourth, I consider only auctions that were the 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, 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 A.5 shows that point estimates are actually larger when I consider only 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.

Fifth, I consider surprises in both whole milk powder (WMP) and skim milk powder (SMP) prices.[41] Because SMP futures were not started until March 2011, this analysis includes a slightly smaller sample. WMP and SMP surprises are 43 percent correlated, though they have the same sign only 71 percent of the time. This means that on 29 percent of the dates, WMP is more expensive than expected, while SMP is less expensive than expected, or vice versa. I do not consider butter or anhydrous milk powder (AMF), the other two products with futures due to the low traded volume of the futures and the

[41] The relevant SMP contract for the forwards contract is medium heat of New Zealand origin.

added complication that AMF and butter are essentially the same product sold in two different formats, making supply forecasts for 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 A.7 shows that only the coefficient on WMP surprises is significant. While I want to be careful in interpreting this result 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. Notably, Bloomberg releases headlines only when WMP prices are announced, not SMP prices. Second, I create a blended surprise measure in which I combine the SMP and WMP surprises using weights equal to total exports of each product in 2010. Table A.8 shows that the elasticity of the exchange rate to this blended measure is almost identical to the elasticity when I consider only WMP price surprises.

Finally, I consider the fact that the Fonterra supply at the auction is not always perfectly predicted in advance. It is critical for the exclusion restriction that surprises come from foreign demand rather than domestic supply, which can embed other information about the domestic economy that could impact the exchange rate. When I restrict my dates to auctions at which supply was perfectly predicted in advance (Table A.9), the coefficients barely differ from my baseline estimates (–0.011 for both the NZD/USD and NZD/AUD exchange rates versus my baseline estimates of –0.010 and –0.009, respectively). Additionally, when I replace the WMP price surprise in Equation 2 with the surprise in supply quantity, calculated as the log difference between Fonterra's pre-announced quantity of CP2 WMP and the amount actually supplied, the result is not significant (Table A.10).

B 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 parity (CIP) deviations should arise as long as the financier's risk-bearing capacity is not a function of exchange rate volatility.[42] 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 three-month CIP deviation between government bond yields in the United States and New Zealand is defined as

$$\Phi_{3m,t} = i^{NZ}_{3m,t} - i^{US}_{3m,t} - \rho^{USD/NZD}_{3m,t} = i^{NZ}_{3m,t} - i^{US}_{3m,t} - \frac{1}{n}(f^{USD/NZD}_{3m,t} - e^{USD/NZD}_{t}),$$

where f_{3m} is the log three-month forward exchange rate, ρ 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

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

premium changes with WMP price surprises:

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

Results are shown in Table A.11.[43] It appears the CIP deviations do not change after WMP price surprises.

Figure A.2 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

$$\rho_{n,t}^{USD/NZD} = irs_{n,t}^{NZ} + bs_{n,t}^{NZ} - irs_{n,t}^{US},$$

where $irs_{n,t}^{NZ}$ denotes the n-year interest rate swap that exchanges a fixed cash flow in New Zealand dollars into the New Zealand three-month bank bill, $irs_{n,t}^{US}$ denotes the n-year interest rate swap that exchanges a fixed cash flow in US dollars into three-month US Libor, and $bs_{n,t}^{NZ}$ denotes the n-year cross-currency basis swap that exchanges the New Zealand three-month bank bill for three-month US Libor.[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.

$$\Delta f_{\tau,a}^{USD/NZD} = \alpha + \beta s_a + \varepsilon_a$$

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

$$\Delta\rho_{\tau,a}^{USD/NZD} = \alpha + \beta s_a + \varepsilon_a$$

[43]In calculating cumulative abnormal returns of the forward premium, I use high-frequency data at the five-minute level instead of the one-minute level.

[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.

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 A.2. We can see from the figure that the spot and three-month forward coefficient estimates are very close to my high-frequency estimates, though standard errors are much larger. None of the forward premiums seems 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 occur primarily 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 long the New Zealand dollar when WMP prices increase and prompt higher demand for the New Zealand dollar, 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 decreases on days when financiers are already short the New Zealand dollar.[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.

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 come from the Commitments of Traders (COT) Reports released by the Commodity Futures Trading Commission (CFTC), and they are based on futures and

[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.

options position data supplied for reporting firms.[46] The COT reports include a breakdown by trader types, and one of these types is "dealer/intermediary." This category aligns with the Gabaix and Maggiori (2015) definition of financier, so I use the data from this category. The data are collected once a week, and to ensure I'm using dealer positions from *before* the auction, I use the last positioning report before the day of the auction (that is, if positioning is reported on auction day, I use the positioning from the preceding week).

Table A.12 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 publicly 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 indicate only that financier positions are primarily taken in over-the-counter markets.

C 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

[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.

good.

Specifically, the model adds a non-traded sector into the small open economy New Keynesian model of Galí and Monacelli (2005).[47] Models that include a traded and non-traded sector are widely used in the open-economy literature (for example, 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 in which a country does not consume any of its own export good.[48]

C.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

[47] Adding a non-traded sector into the model of Galí and Monacelli (2005) has also been done in other papers (Corsetti, Dedola and Leduc, 2008; Santacreu, 2014; Guo, Ottonello and Perez, 2020).

[48] 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.

consumption

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

where $\lambda \in [0,1]$ is the share of the non-traded good in consumption in a 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

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

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:

$$P_t C_t + \mathbb{E}_t[F_{t+1} B_{t+t}] = B_t + W_t L_t + T_t,$$

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. Lowercase variables denote logs. The second of these two conditions is the Euler condition for nominal bonds.

C.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

$$w_t - p_{j,t} = mc_{j,t} + a_{j,t} \quad j \in H, N,$$

where $mc_{j,t}$ denotes the marginal cost of sector j. Each sector contains a continuum of firms, and each firm supplies its 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

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

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

$$\pi_{j,t} = \kappa mc_{j,t} + \beta \, \mathbb{E}_t[\pi_{j,t+1}] \quad j \in H, N,$$

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

$$a_t = (1-\lambda)a_{H,t} + \lambda a_{N,t}.$$

C.3 Rest of the World

The rest of the world trades goods and financial securities with the home economy. It provides 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 auto-regressive 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:

$$p^*_t = p^*_{F,t}$$

C.4 Exchange Rates and the Terms of Trade

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

$$S_t = \frac{P_{H,t}}{P_{F,t}}.$$

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:

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

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 (that is, 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,

$$\Delta e_t = -\Delta s_t + \pi_{H,t} - \pi^*_{F,t}. \tag{8}$$

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 its good in foreign currency terms, that is, $\pi^*_t = \pi^*_{F,t} = 0$, then the nominal exchange rate should appreciate 1-for-1 with terms of trade increases.

C.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:

$$C_t = \vartheta C^*_t Q_t^{\frac{1}{\sigma}},$$

where ϑ 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:

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

C.6 Monetary Policy

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

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

$$i_t = \rho + \phi \pi_t.$$

C.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 $\{Y_t, Y_{H,t}, Y_{N,t}, C_t, C_{H,t}, C_{N,t}, C_{F,t}, L_t, L_{H,t}, L_{N,t}\}$, 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. *Households' choices solve their maximization problem given the equilibrium prices and interest rate (household optimization).*
2. *Firms' choices solve cost minimization (firm optimization).*
3. *Interest rates satisfy the UIP condition.*
4. *The price of the foreign tradable good F satisfies the law of one price $P_{F,t} = E_t P^*_{F,t}$.*
5. *All markets clear.*

C.8 Parameterization

The first set of parameters is set to the values in Galí and Monacelli (2005).[49] These parameter values are shown in the first panel of Table A.13. 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 the 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 through 2019.

[49]Because Galí and Monacelli (2005) does 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.

C.9 Impulse Responses and Discussion

To examine the response to a foreign demand shock, I simplify the model to the case where productivity in both sectors is 1 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 A.3.

As we can see, the immediate impact of the shock is a nominal exchange rate appreciation that moves 1-for-1 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, it 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 the demand shock.[50]

It is straightforward to modify the model so that total exports H are an aggregator of two export goods: dairy and an additional export good, production of which is given simply 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 percent of the export sector, then a 1 percent rise in the terms of trade should cause a 0.1 percent nominal exchange rate appreciation. This is larger than the coefficient I obtain 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.

[50] 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.

	Cumulative Δe			
	(1) NZD/USD	(2) NZD/USD	(3) NZD/AUD	(4) NZD/AUD
Surprise Δ WMP	-0.009^{***}	-0.011^{***}	-0.009^{***}	-0.011^{***}
	(0.002)	(0.002)	(0.001)	(0.001)
Expected Δ WMP		-0.005^{**}		-0.005^{***}
		(0.002)		(0.001)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	212	209	212	209
R2	0.094	0.110	0.177	0.207

Table A.1: **Elasticity estimates, calculated with cumulative returns instead of cumulative abnormal returns.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1) NZD/USD	(2) NZD/USD	(3) NZD/AUD	(4) NZD/AUD
Surprise Δ WMP	−0.010**	−0.012**	−0.009**	−0.011***
	(0.004)	(0.005)	(0.004)	(0.004)
Expected Δ WMP		−0.004		−0.005**
		(0.004)		(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	212	209	212	209
R2				

Table A.2: **Elasticity estimates, adjusting for autocorrelation in surprises.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1) NZD/USD	(2) NZD/USD	(3) NZD/AUD	(4) NZD/AUD
Surprise Δ WMP	−0.009***	−0.013***	−0.009***	−0.012***
	(0.003)	(0.003)	(0.002)	(0.002)
Expected Δ WMP		−0.009***		−0.008***
		(0.003)		(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	122	120	122	120
R2	0.085	0.153	0.161	0.253

Table A.3: **Elasticity estimates for the subsample of dates before the Insights package was released on February 16, 2016.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
Surprise Δ WMP	−0.002	−0.005	−0.007**	−0.008**
	(0.006)	(0.006)	(0.003)	(0.003)
Expected Δ WMP		−0.010*		−0.005
		(0.006)		(0.003)
Constant	0.000	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	212	209	212	209
R2	0.001	0.013	0.023	0.027

Table A.4: **Elasticity estimates using an event window that spans the entirety of the GDT auction.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
	n=1	n=2	n=1	n=2
Surprise Δ WMP	−0.015***	−0.006**	−0.013***	−0.007***
	(0.003)	(0.003)	(0.002)	(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	103	109	103	109
R2	0.151	0.049	0.252	0.112

Table A.5: **Elasticity estimates depending on auction number in a month.** Columns (1) and (3) display results using only data from the first auction in each month. Columns (2) and (4) display results using only data from the second auction in each month. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
	n=1	n=2	n=1	n=2
Surprise Δ WMP	−0.014***	−0.011**	−0.015***	−0.009***
	(0.005)	(0.004)	(0.003)	(0.003)
Constant	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	94	97	94	97
R2	0.077	0.065	0.199	0.071

Table A.6: **Elasticity estimates depending on auction number in a month, after winsorizing observations at the 5th and 95th percentiles.** Columns (1) and (3) display results using only data from the first auction in each month. Columns (2) and (4) display results using only data from the second auction in each month. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
Surprise Δ WMP	−0.011***	−0.012***	−0.010***	−0.012***
	(0.002)	(0.003)	(0.002)	(0.002)
Surprise Δ SMP	0.002	0.001	0.002	0.002
	(0.002)	(0.002)	(0.001)	(0.002)
Expected Δ WMP		−0.004		−0.006***
		(0.003)		(0.002)
Expected Δ SMP		−0.001		0.002
		(0.003)		(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	203	200	203	200
R2	0.100	0.114	0.180	0.198

Table A.7: **Elasticity estimates taking WMP and SMP price surprises into account.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder and skim milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
Surprise Δ WMP+SMP	−0.010***	−0.012***	−0.009***	−0.010***
	(0.002)	(0.003)	(0.002)	(0.002)
Expected Δ WMP		−0.002		−0.004**
		(0.003)		(0.002)
Expected Δ SMP		−0.004		−0.001
		(0.002)		(0.002)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	203	200	203	200
R2	0.077	0.099	0.133	0.149

Table A.8: **Elasticity estimates to a blended metric of WMP and SMP price surprises.** The blended surprise metric uses weights equal to total exports of whole milk powder (WMP) and skim milk powder (SMP) in 2010. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder and skim milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe			
	(1)	(2)	(3)	(4)
	NZD/USD	NZD/USD	NZD/AUD	NZD/AUD
Surprise Δ WMP	−0.011***	−0.015***	−0.011***	−0.012***
	(0.003)	(0.004)	(0.002)	(0.002)
Expected Δ WMP		−0.007*		−0.005*
		(0.004)		(0.003)
Constant	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	94	92	94	92
R2	0.101	0.142	0.214	0.210

Table A.9: **Elasticity estimates on days when supply is perfectly predicted.** This table considers only days when the Fonterra supply of CP2 at the auction does not differ from the expected supply of CP2 (that is, when the log difference is less than 0.001). Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	Cumulative abnormal Δe	
	(1)	(2)
	NZD/USD	NZD/AUD
Surprise Δ supply WMP	−0.001	0.002
	(0.004)	(0.003)
Constant	0.000	0.000
	(0.000)	(0.000)
Observations	188	188
R2	0.000	0.004

Table A.10: **Elasticity of the exchange rate to surprises in auction supply quantity.** The surprise change in supply quantity is calculated as the log difference between Fonterra's preannouced quantity of CP2 whole milk powder (WMP) and the amount actually supplied at the auction. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise changes in the supply of whole milk powder are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.

	$\Delta\rho_{3m}$	
	(1)	(2)
Surprise Δ WMP	-0.000	-0.000
	(0.000)	(0.000)
Expected Δ WMP		-0.000
		(0.000)
Constant	$1.040{\times}10^{-06}$*	$1.272{\times}10^{-06}$**
	$(5.659{\times}10^{-07})$	$(5.720{\times}10^{-07})$
Observations	212	209
R2	0.000	0.000

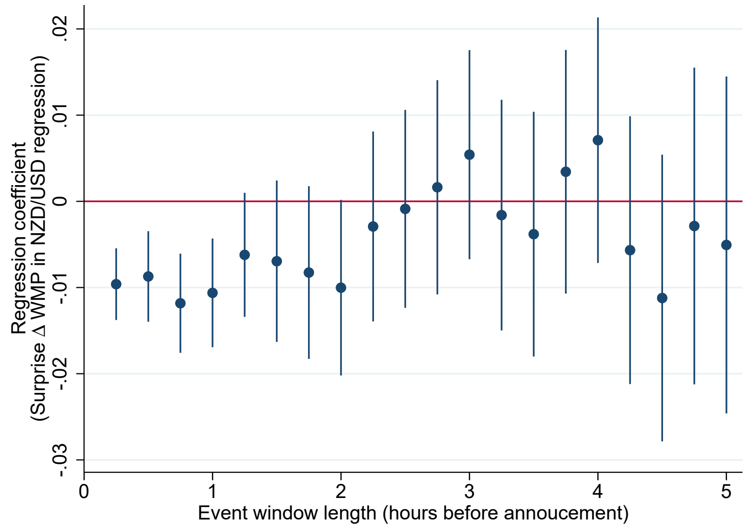
Table A.11: **The impact of surprise WMP price changes on the CIP wedge within 15 minutes after the announcement.** Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Surprise and expected changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute spot exchange rate data come from histdata.com, while high-frequency interest rate swap, cross-currency basis swap, and exchange rate forward data come from Bloomberg. Auction announcement times were collected from Bloomberg.

	Δe			
	(1) NZD/USD same posn	(2) NZD/USD opposite posn	(3) NZD/AUD same posn	(4) NZD/AUD opposite posn
Surprise Δ WMP	−0.010***	−0.010***	−0.010***	−0.009***
	(0.003)	(0.003)	(0.002)	(0.002)
Constant	−0.000	0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	106	106	106	106
R2	0.083	0.100	0.164	0.180

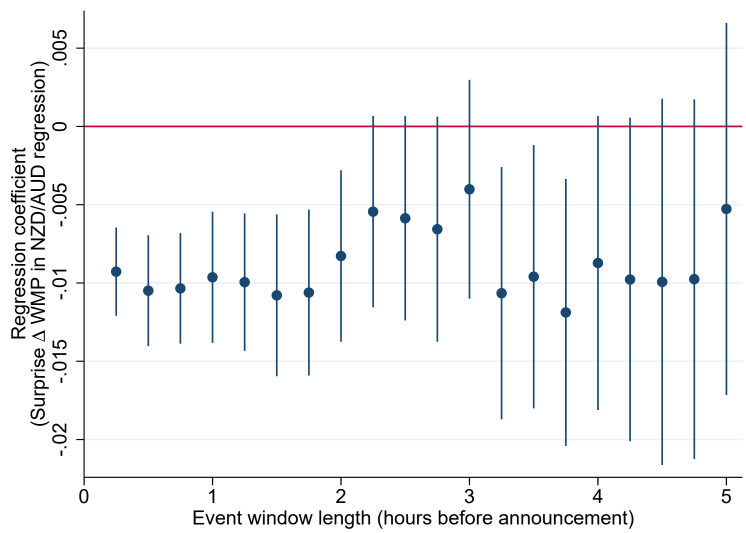
Table A.12: **The impact of surprise WMP price changes on the New Zealand dollar within 15 minutes after the announcement and depending on whether dealers were long or short the New Zealand dollar in the days before the announcement.** "same posn" indicates days when dealers were long the New Zealand 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 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 when 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 the opposite position from what they already had on their books. Positioning data come from the Commitments of Traders (COT) Reports released by the Commodity Futures Trading Commission (CFTC), and they are based on futures and options position data supplied for reporting firms. 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. Surprise changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg. Coefficients are displayed with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Parameter	Description	Value
Panel 1: Parameters set following the literature		
σ	Inverse intertemporal elasticity of substitution	1
ψ	Inverse Frisch elasticity of labor supply	3
η	Intratemporal elasticity of substitution, H vs. F	1
ν	Intratemporal elasticity of substitution, T vs. NT	1
β	Discount factor	0.99
θ	Calvo parameter	0.75
ϕ	Taylor rule inflation coefficient	1.5
Panel 2: Parameters calibrated to New Zealand		
α	Fraction of foreign goods in tradable goods consumption basket	0.5
λ	Fraction of non-tradable goods in consumption basket	0.56
Panel 3: Parameters calibrated to the US		
ρ_{Y^*}	Foreign demand shock persistence	0.84
σ_{Y^*}	Foreign demand shock std.	0.013

Table A.13: **Model parameters.** This table gives the parameters used in the model in Section C. The first set of parameters is set to the values in Galí and Monacelli (2005). 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 the 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 through 2019.

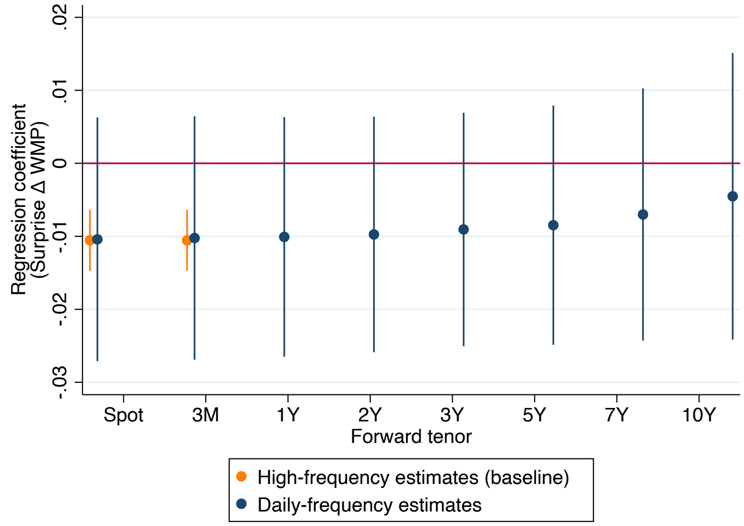


(a) USD/NZD

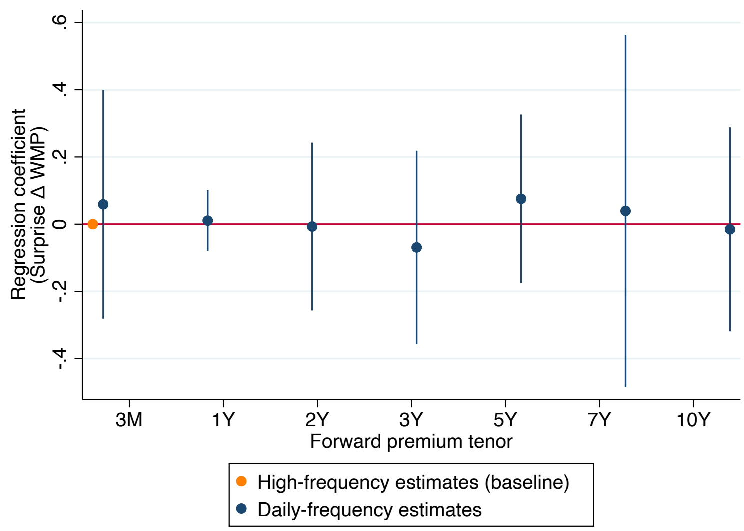


(b) AUD/NZD

Figure A.1: **The effect of surprise increases in WMP prices on the NZD exchange rate with a backward-lengthening event window.** Bars denote 95% confidence intervals. Surprise changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute exchange rate data come from histdata.com. Auction announcement times were collected from Bloomberg.



(a) Forward rates



(b) Forward premiums

Figure A.2: **The effect of surprise increases in WMP prices on the USD/NZD forward rates and forward premiums of various tenors.** This figure shows the regression coefficient when regressing the forward rate or the forward premium on the surprise metric for various tenors. Bars denote 95% confidence intervals. Surprise changes in whole milk powder prices are calculated using auction price data from Global Dairy Trade (GDT) and futures data from New Zealand's Exchange (NZX). Minute-by-minute spot exchange rate data come from histdata.com, while high-frequency interest rate swap, cross-currency basis swap, and exchange rate forward data come from Bloomberg. Auction announcement times were collected from Bloomberg.

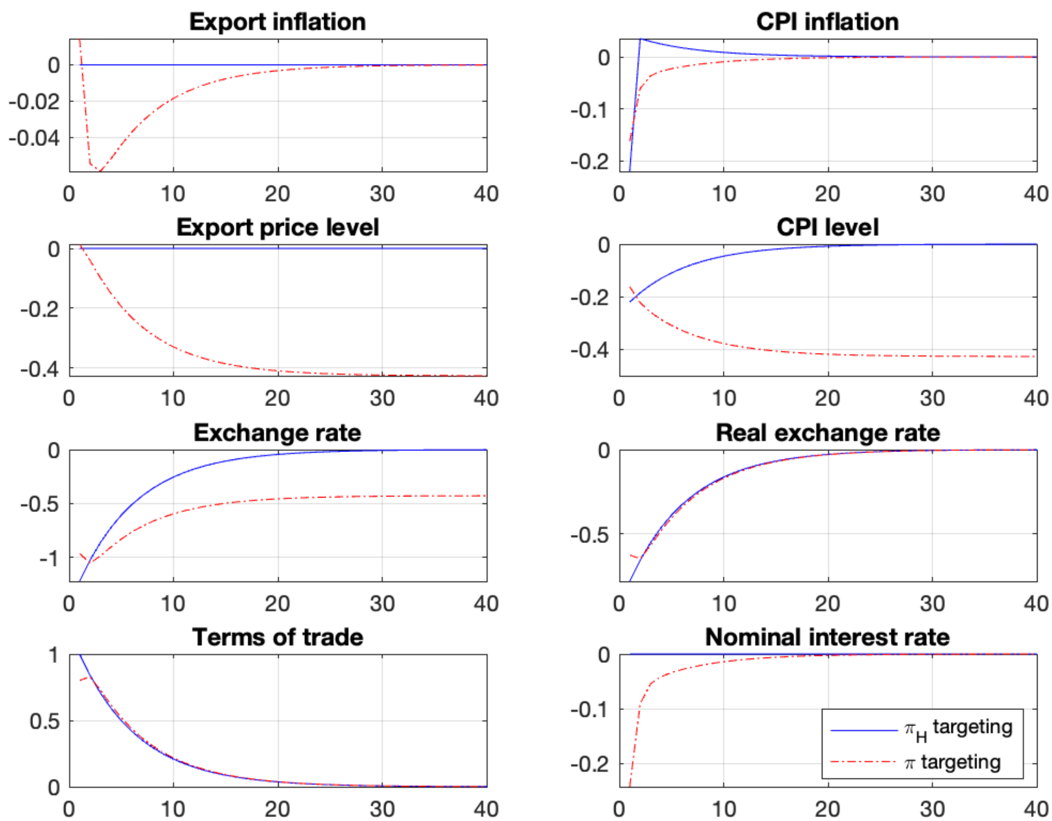


Figure A.3: **Impulse response to a 1% foreign demand shock for the export good.** This figure shows how the nominal exchange rate may remain appreciated following a temporary foreign demand shock. The model was calculated using parameters per Table A.13.