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Do spot market auction data help price discovery?

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ABSTRACT

This paper contributes to the price discovery literature by establishing, for the first time, the role of commodity spot market auction data. Using the New Zealand whole milk powder market as an example, we show that auction-level data explain the price discovery dynamics above and beyond determinants previously identified as being relevant to spot and futures market price formation. In particular, the price discovery of the futures market rises with the volume of dairy products traded at the auction, signaling that the volume auctioned induces a change in the trading strategies of futures market participants. The whole milk powder discovery process is found to primarily take place in the spot market, which aligns well with the auction predating the introduction of the futures market, its higher volume, and lower trading costs.

1. Introduction

Relying on the notion that prices ought to incorporate timely information efficiently, the literature on price discovery analyzes closely-related assets (such as a commodity and its futures contract), determines which market leads price formation, and studies the determinants of the price discovery process.[1] This paper contributes to this literature by studying the role of auction market data in price discovery. Auction-level data include the volume of a physical commodity sold or bought at the auction and are therefore direct measures of supply and demand in the physical market. As price determinants, these variables are natural candidates for inclusion in the set of factors that could facilitate price discovery.

Bearing this objective in mind, we use a unique dataset of auction-level variables that pertain to New Zealand's dairy spot market. To the best of our knowledge, previous price discovery studies in commodities omit information coming from auction-level activities in the spot market and thus, testing whether auction-level activity influences price discovery is a unique contribution of this paper. More specifically, our auction dataset includes the actual volume of whole milk powder (WMP) sold at the auction, the under-subscription

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[1] See, for example, Eun and Sabherwal (2003), Chen and Gau (2010), Arzandeh and Frank (2019), Wallace et al. (2019), Bohl et al. (2020), Bohmann et al. (2019), Entrop et al. (2020).

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level of the auction, the total volume of dairy products bought, the number of qualified or winning bidders, the number of bidding rounds, and the duration of the trading event. As proxies for supply and demand, these auction characteristics are natural candidates for determining spot prices (see e.g. MacDonald et al., 2002; Crespi and Sexton, 2004)[2] and could potentially have an impact on price discovery in the physical market. Alternatively, these auction-level data could enhance the information set available to futures market participants by providing them with information not already encapsulated in futures market data. If this occurs, auction data from the spot commodity market could contribute to the price discovery of the futures market.

Our decision to study New Zealand's WMP market also reflects the leading role of New Zealand in the global dairy trade. For example, New Zealand is the world's largest whole milk powder and butter producer, representing 56% and 43% of global exports between 2018 and 2020 (OECD-FAO Agricultural Outlook 2021–2030, 2021). Likewise, 77% of the volume of dairy products auctioned in New Zealand over the period October 2010 to July 2018 was exported to countries located outside the South-East Asia and Oceania region; this serves to further corroborate New Zealand as a global dairy leader.

Following the literature on price discovery, we begin by measuring the component share of Gonzalo and Granger (1995) and the information share of Hasbrouck (1995) to determine which market contributes the most to the fundamental (or implicit) price common to both markets. The data point towards a predominant role of the spot market: the component (information) share of the spot market averages 0.83 (0.88) across futures contract maturities and the dominance of the spot market is unchallenged when considering 3-year rolling windows of observations. We attribute the dominance of the spot market in terms of price discovery to various factors, including the earlier inception of the spot auction platform relative to the introduction of the first futures contract, as well as the higher volume and lower transaction costs of the auction market relative to those of the futures market.

To better understand the drivers of price discovery, we then regress the time-varying price discovery measures from the futures market onto spot market auction data, as well as various factors shown to impact price discovery in the extant literature. We note the information coming from spot auction data adds 6% explanatory power on average across model specifications and thus contributes to explaining the price discovery dynamics. In particular, a larger volume bought by winning bidders across all dairy products implies better transmission of information to the futures market (at the 1% level of statistical significance) and thus increases the price discovery of the futures market. We explain this mechanism as follows. Spot auction bidders have access to the dairy volume offered in the auction (or dairy supply) well in advance of the start of the auction (Rules C2.10 and C2.11 in the GDT Trading Event Rules, August 2022). With this information at hand, during weeks when the dairy supply increases, and accordingly, the volume of winning bidders rises, spot returns tend to drop,[3] pushing rational speculators in the futures market to take shorter futures positions than they would otherwise (to benefit from the anticipated price drop). Likewise, it is then rational for dairy producers (consumers) with advanced information about an increase in the dairy supply before the GDT auction to engage in selective hedging by taking shorter (less long) futures positions than dictated by purely risk-minimizing considerations. In other words, a rise in the volume of winning bidders seems to induce a change in the strategies that futures market participants follow, thereby raising the price discovery of the futures market.

Our paper contributes first and foremost to the price discovery literature by highlighting the role of spot market auction information. As such it adds to the set of factors that have been shown to have an impact, such as i) liquidity proxies: trading volume, bid-ask spread, or the steps of the limit-order book beyond the best bid-ask spreads, ii) futures markets factors: roll-yield, open interest, hedging pressure, speculative activity, or skewness, and iii) market sentiment (see, e.g., Eun and Sabherwal, 2003; Chen and Gau, 2010; Lin et al., 2018; Arzandeh and Frank, 2019; Wallace et al., 2019; Bohl et al., 2020; Bohmann et al., 2019; Entrop et al., 2020). By showing that the price discovery process for WMP takes place predominantly in the spot market, our paper also adds analysis of the dairy market to the evidence presented thus far. There seems to be no clear consensus in the literature as to which market leads price discovery, with conclusions depending on the underlying asset considered. For example, some papers find that price discovery takes place predominantly in futures markets (Stoll and Whaley, 1990; Chan, 1992; Jin et al., 2018; Lin et al., 2018; Bohl et al., 2020)[4] while other papers argue the opposite (Chen and Gau, 2010; Dolatabadi et al., 2015; Dimpfl et al., 2017; Narayan and Sharma, 2018).

The article unfolds as follows. Section 2 presents the bidding process that determines spot prices, some background information on New Zealand dairy futures markets, as well as our unique spot auction dataset. Section 3 introduces the methodologies employed to measure price discovery and to explain its dynamics. Section 4 presents the empirical results and finally, Section 5 concludes.

2. Background information on whole milk powder markets

This section provides specifics on WMP traded on the GDT (Global Dairy Trade) platform, its derivatives traded on the New Zealand Exchange (NZX) Dairy Derivatives Market, and the determinants of price discovery.

[2] For example, Crespi and Sexton (2004) compare simulated and actual auction prices of four Texan beef-processing plants and find lower actual prices may be attributed to auction characteristics (e.g., number of lots available) and non-economic factors (including interpersonal relationships between buyers and sellers). In a similar vein, MacDonald et al. (2002) find auction prices fall as the number of bidders increases in five commodity futures (all-purpose flour, bakery flour, pasta products, vegetable oil, and peanut butter), suggesting the number of bidders matter for price determination.

[3] This is confirmed by the large negative Pearson correlation between spot returns and the log changes in the volume bought by winning bidders, which equals −43.28% over the sample analyzed.

[4] The relatively higher leverage of futures markets, their relatively lower trading costs and their absence of short-selling restrictions are amongst the reasons typically put forward for the leading role of futures markets.

2.1. Global dairy trade and NZX whole milk powder futures

The GDT platform was created in 2008 by Fonterra Cooperative Group Ltd. (Fonterra), New Zealand's largest dairy company, as a dairy trading platform. Today, it is owned and managed by a strategic partnership between the European Energy Exchange (EEX), Fonterra, and New Zealand's Exchange (NZX). The mechanism is an ascending-price clock auction, where the trading manager announces the offer volume and starting price for a given commodity set by the seller, and participating buyers subsequently enter the volumes they are willing to buy for that price (Global Dairy Trade, 2016). In simple terms, if the quantity demanded exceeds or falls short of the quantity supplied, the trading manager will change the price in the following bidding rounds and buyers will readjust their bid volumes based on this new price. This process is repeated until supply and demand at the auction are in equilibrium. The price that clears the market is announced as the official auction (spot) price for that commodity and will be the price that all winning buyers pay.

In 2018, more than 500 registered buyers on the auction platform from Africa, Europe, the Middle East, North America, North Asia (i.e., China), South and Central America, as well as South East Asia, could bid for dairy commodities at twice-monthly auction events. With an annual trade volume of more than 860,000 metric tons and the corresponding yearly trade value averaging three billion US dollars between 2014 and 2018 (Global Dairy Trade, 2018), GDT auction results are widely used and recognized as important spot price references on global, regional, and local dairy markets. Further evidence of New Zealand's leadership in the global dairy market can be found in Appendix A.

The portfolio of dairy products offered by sellers on GDT is diverse, with contract periods – that is, times of shipment – ranging between one month and six months from the GDT auction month. Our article is concerned solely with WMP as it represents 52% of the total volume sold of GDT trades as of 2018, and thus, it is the most important dairy commodity traded on GDT. Specifically, our spot market contracts are those WMP contracts traded on GDT with a two-month time of shipment (or Contract 2, e.g. a July 2018 GDT auction ships the physical asset two months later in September 2018). These are the most liquid WMP contracts at the GDT auction and the underlying asset of the NZX WMP futures contract. The GDT dataset is not publicly available and covers GDT auctions from October 2010 to July 2018. Fig. 1 plots the volume of WMP sold from October 2010 to July 2018 at GDT auctions. The quantities offered follow a seasonal pattern due to the New Zealand milk production curve.[5]

The first WMP futures contract was launched in October 2010 on the NZX Dairy Derivatives Market, as volatile dairy prices continued to motivate the creation of risk management tools, allowing global and local dairy market participants to hedge against future price variation. The cumulative volume of trading of WMP futures as of July 2018 represents 71% of the trading volume of all dairy futures contracts offered by NZX. The large trading volume of WMP futures contracts results from the dominant position of New Zealand in the global WMP export market, an observation that motivated our decision to analyze price discovery in the WMP market only (see Appendix A for further detail). We collect the settlement prices and volume of NZX WMP futures from the NZX Research Centre.

Fig. 2 presents a timeline for the collection of the futures and spot auction data. Our baseline results match the auction price obtained at the beginning of day t with the futures settlement prices at the close of day t-1.[6] This choice was governed by our desire to have the two prices measured over the shortest possible time span. We note, however, that our conclusions on price discovery and its drivers are unchanged when considering settlement futures prices on day t in place of those on day t-1 (as portrayed on the right-hand side of Fig. 2). These results are reported in Section 4.4.2.

NZX offers WMP futures contracts with maturities ranging from one month ahead to 16 months ahead in increments of one month. We form continuous series of futures prices for the n^{th}-nearest maturity contract by assuming we hold that contract up to the last twice-monthly observation of trading of the front-end contract and then roll the position to the $n+1^{th}$-nearest contract. This practical solution introduces a bias in the continuous futures price series that depends on the roll-yield at time t; i.e., $F_{t,n} - F_{t,n+1}$ where $F_{t,n}$ denotes the daily price of the n^{th} maturity contract on the roll date, t. To remove this bias, we regress the continuous time series of daily futures prices on a constant and a roll-yield dummy equal to 1 on the roll date and 0 otherwise. The residuals plus the constant of that regression are used as a proxy for the daily continuous price on the n^{th}-nearest maturity futures contract.

All data are at a daily frequency, aside from the auction data and the spot GDT prices that are twice-monthly. The sample period spans October 19, 2010 (the inception of the NZX WMP futures contract) through July 17, 2018. The futures contract settles to the arithmetic average of the corresponding twice-monthly GDT prices from the GDT auction month. There are four days in our sample where GDT did not publish WMP prices: July 15, 2015; August 4, 2015; November 3, 2015; March 7, 2017. We omit the outlier months of July–August 2015, November 2015, and March 2017 where the futures contract prices were determined by only one GDT event. Prices were not published because bidding during the auction was insufficient to cause the announced price to rise above the starting

[5] Results from a regression of the change in total volume on monthly dummies highlight significant increases in volume sold in the southern hemisphere winter months (July–August) where these months correspond to periods of abundant rain and thus, cheaper cow feeds.

[6] The auction event starts at 12:00 a.m. NZST (New Zealand Standard Time) of day t, ending on average around 2 and a half hours later on the same day.

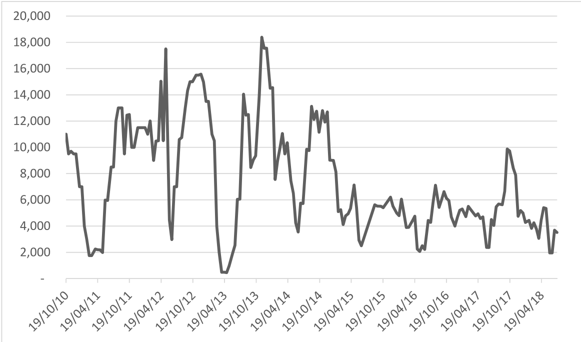

Fig. 1. Total volume of WMP sold at GDT auction event.

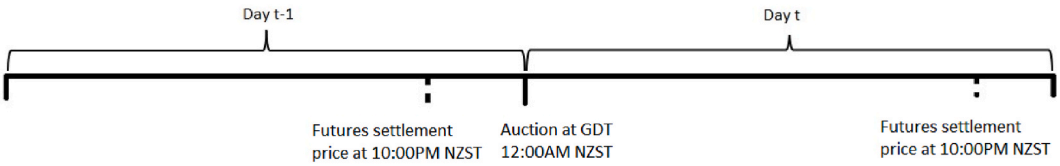

Fig. 2. Illustration of matching GDT and futures data.

price (Stein, 2022).[7] The final sample contains 179 auction events.

Table 1 presents summary statistics for the matched spot prices and continuous futures prices with fixed maturities ranging from one to 16 months. The futures prices are on average higher the more distant the maturity of the contract, suggesting the presence of contango. The Samuelson effect is present in the data: the shorter the contract maturity, the higher the standard deviation of the futures price, at least up to the 8^{th} maturity.[8] As expected, the correlations between the spot and futures prices are close to one and tend to drop as maturity rises (due to basis risk).

Table 1 also reports three measures of liquidity: *i*) Zeros of Lesmond et al. (1999) which measures the proportion of days with zero futures returns over the preceding two GDT auctions, *ii*) the Amivest measure of Amihud et al. (1997) which divides the dollar volume on day *t* by the absolute futures return on day *t* and averages this over the preceding two GDT auctions, and *iii*) the contract's total daily volume over the preceding two GDT auctions. The three measures are calculated over any two consecutive GDT auctions and then averaged over the whole sample. The contracts with maturities ranging from one to six months are found to be the most liquid and are therefore shortlisted for our analysis of price discovery.

Fig. 3 plots the evolution of GDT and the first six NZX WMP futures contract prices over our sample period. There are large variations in price; e.g., a peak in early 2013 due to supply-side constraints with drought in New Zealand coinciding with challenging production conditions globally, followed by a decline in 2014 as production stabilized with the end of drought conditions. As expected, the GDT and futures prices track each other well.

2.2. *Determinants of price discovery*

The GDT and NZX price datasets allow the assessment of whether price discovery in the WMP market takes place in the spot or futures markets. To identify quantitatively the drivers of price discovery, we use four categories of information variables as summarized in Table 2. These variables can be broadly categorized into measures of *GDT auction data* (Panel A), *futures market activity* (Panel B), *milk market pricing and sentiment* (Panel C) and *seasonality and trend* (Panel D).

The first category pertains to GDT auction data. Two types of auction-level data are considered. The first type captures the supply

[7] There are two main explanations for the final price not exceeding the auction starting price. In 2017, improved weather conditions meant Fonterra revised its supply upwards (i.e., they collected more milk than previously expected), see Morrison, (2017). In 2015, there were both supply-side and demand-side factors placing a ceiling on the GDT price. For supply, New Zealand experienced two high-supply seasons *and* the European Union and China both experienced strong supply seasons (Lin and Piddock, 2015). At the same time, demand fell from New Zealand's main buyer China, and the Middle East and emerging nations, due to slowing economies and in China's case, strong domestic supply (Reuters. July 16, 2015).

[8] The higher volatility for maturities longer than 8 months may be due to the very low liquidity of these contracts as shown in Table 1.

Table 1
Summary statistics for the WMP spot and futures prices.

	Mean	StDev	Skewness	Excess kurtosis	Correl(S_t, $F_{t,n}$)		Liquidity measures		
							Zeros	Amivest	Volume
SpotFutures	3323.32	932.93	0.9315	0.6178					
1st	3337.21	887.65	0.7934	0.3806	0.98	(0.00)	66.55	16,34,94,006	463.41
2nd	3364.36	819.17	0.7192	0.3439	0.97	(0.00)	55.01	16,87,28,929	696.07
3rd	3376.23	757.16	0.5857	−0.0451	0.96	(0.00)	54.73	18,61,41,868	657.97
4th	3382.82	704.97	0.4758	−0.3290	0.95	(0.00)	59.39	16,33,82,195	516.96
5th	3391.15	674.73	0.4598	−0.3394	0.94	(0.00)	63.41	13,33,27,791	396.92
6th	3393.32	657.44	0.5625	−0.1599	0.92	(0.00)	71.83	9,04,43,224	254.88
7th	3410.31	669.15	0.8035	0.4348	0.91	(0.00)	83.06	5,30,24,148	123.92
8th	3419.58	677.90	0.9356	0.6023	0.90	(0.00)	87.41	3,84,08,920	66.32
9th	3412.88	713.56	0.9043	0.4174	0.90	(0.00)	92.84	2,61,85,554	33.26
10th	3372.43	755.01	0.7323	0.2433	0.91	(0.00)	95.64	1,44,15,600	13.91
11th	3356.51	783.42	0.7019	0.0866	0.92	(0.00)	97.86	79,81,752	7.15
12th	3358.72	810.33	0.6972	0.0534	0.92	(0.00)	99.02	19,89,663	2.08
13th	3360.45	810.42	0.6893	0.0475	0.92	(0.00)	99.53	19,75,354	0.66
14th	3357.65	811.63	0.6945	0.0403	0.93	(0.00)	99.78	19,68,773	0.05
15th	3357.23	811.87	0.6950	0.0385	0.93	(0.00)	99.84	19,68,712	0.01
16th	3358.44	811.50	0.6919	0.0396	0.93	(0.00)	99.34	–	0.00

The table presents summary statistics for the WMP spot and futures prices (S_t and $F_{t,n}$ with maturity n, respectively) and correlation coefficients between the two with associated *p*-values in parentheses. It also reports three measures of liquidity: Zeros of Lesmond et al. (1999), Amivest of Amihud et al. (1997) and the total volume of trading between two GDT auctions. The sample covers the period from October 2010 to July 2018.

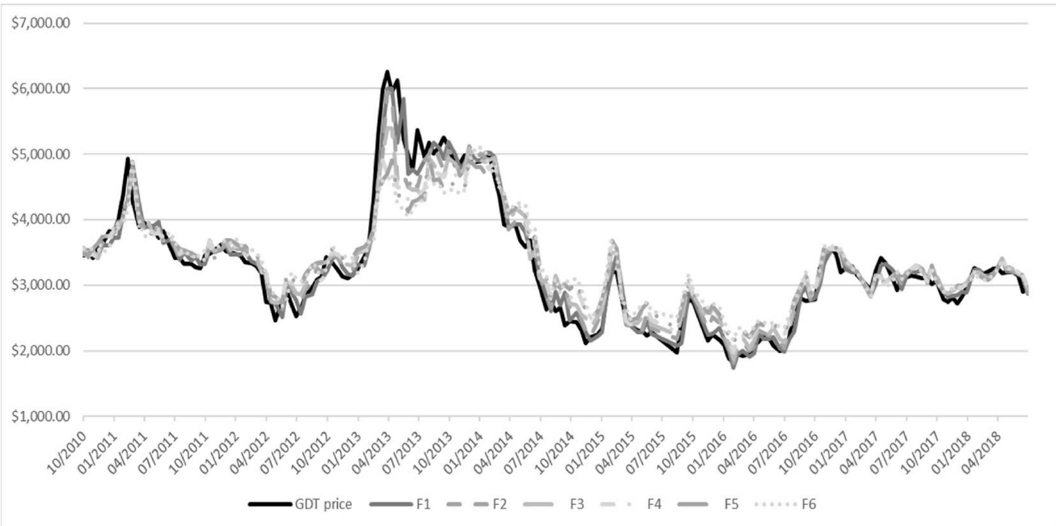

Fig. 3. GDT and WMP futures prices.

and demand of *WMP* via 1) the actual volume of WMP sold at the GDT auction and 2) the level of under-subscription of the auction.[9] The second type considers data on bidder participation for *all* dairy products and includes 1) the total volume bought across regions and across dairy commodities, 2) the changes in the overall count of qualified bidders,[10] 3) the overall count of winning GDT bidders, 4) the number of bidding rounds, and 5) the duration of trading (auction) events. To determine whether certain groups of buyers influence the price discovery process more than others, we replace the total volume bought aggregated across regions with the volume bought disaggregated per region; the regions considered are Africa, Europe, North America, South and Central America, North Asia (i.e., China), South-East Asia and Oceania, as well as the Middle East. All this information is available across all dairy commodities, WMP

[9] We define the level of under-subscription as the percentage difference between the maximum volume offered and the actual volume of WMP sold at the GDT auction. However, we note the sellers at GDT set a minimum and maximum volume to be sold. Therefore, the correct terminology is: if the volume sold is between the minimum and maximum amount, this is called the *subscribe status*; volume sold below the minimum amount is called *undersubscribed*; and finally, over the maximum is called *oversubscribed*.

[10] The series of the overall count of qualified bidders is nonstationary according to an unreported ADF test, so we use its changes.

Table 2
Determinants of price discovery.

Name	Definition
Panel A: GDT auction data	
WMP-specific auction	Actual volume of WMP sold at GDT event (*)
	Level of under-subscription of the auction (percentage difference between the maximum volume offered and the actual volume of WMP sold at GDT event)
Overall non WMP- specific GDT auction	Total volume bought by winning bidders (*)
	Changes in the number of qualified bidders (*)
	Number of winning bidders (*)
	Number of bidding rounds (*)
	Duration of trading event (*)
Regional non WMP-specific GDT auction	Volume bought by winning bidders at the regional level (*)
Panel B: Futures market activity	
Roll-yield	$\ln(F_{t,1})$ - $\ln(F_{t,2})$
Lesmond et al. (1999) liquidity measure	Proportion of zero price change over the preceeding 2 GDT events
Amivest liquidity measure	$Volume of specific contract at GDT event divided by absolute futures return over the preceeding 2 GDT events
Skewness	Skewness of corresponding daily futures returns over the year preceeding GDT event
Volatility	STD of corresponding daily futures returns over the preceeding 2 GDT events
Volume	Volume of specific contract averaged over the preceeding 2 GDT events
Panel C: Milk market pricing	
Milk market price	Milk price index at the time of the GDT event (expressed as Fisher index to avoid biases due to GDT volume shifts between high and low value commodities) (**)
Milk market risk	Absolute milk price index return since previous GDT event
Sentiment	Dummy variable set to 1 when CBOE VIX is above its whole-sample 75th percentile
Panel D: Seasonality and trend	
Month dummy	Monthly dummy variables
Trend	Time trend
GDT event dummy	Dummy variable set to 1 on the second GDT event of a given month

The table details the series used as determinants of price discovery. Regional data pertain to the following regions: Africa, Europe, Middle East, North America, North Asia, South- and Central America, South East Asia and Oceania. $F_{t,1}$ and $F_{t,2}$ represent the futures prices at time t of the front and second-nearest contracts, respectively. (*) means that the variable has been transformed as ln(1+variable). (**) means that the variable has been transformed as ln(variable).

bids included. We believe, however, that proxying WMP bids by the bids for all dairy products is legitimate given that WMP represents the most liquid dairy commodity contract traded on GDT with the largest volume (52% as of 2018).

The second variable category follows the literature in assuming that futures market characteristics impact price discovery. We include factors such as the roll-yield (Bohl et al., 2020),[11] liquidity (Eun and Sabherwal, 2003; Lin et al., 2018), skewness (Bohmann et al., 2019), volatility (Eun and Sabherwal, 2003; Chen et al., 2016; Lin et al., 2018; Bohmann et al., 2019) and trading volume (Chen et al., 2016; Lin et al., 2018; Bohmann et al., 2019; Bohl et al., 2020), as they have been shown to determine commodity futures contracts' pricing and to influence price discovery.

It is possible that general dairy market conditions also impact the price discovery process, therefore the third variable category contains characteristics pertaining to the dairy market in general and not to the WMP market in particular. These variables include the milk market price index (measured as the weighted average value of all products sold at a GDT auction), the milk market price index volatility (measured as the absolute log changes in the milk market price index), and a general market sentiment variable (a dummy variable set to 1 when CBOE VIX is above its whole-sample 75^{th} percentile; VIX was downloaded from Refinitiv Datastream) that captures how optimistic or pessimistic agents are (Lin et al., 2018). The inclusion of this variable reflects the fact that the price discovery of futures markets tends to diminish in high sentiment periods due to limits to arbitrage (Lin et al., 2018).

Finally, the last category includes seasonality and trend variables that decipher whether price discovery follows the New Zealand dairy production pattern, and therefore, differs between months (monthly dummies), trends up or down over time (linear trend) or is specific to the first or second monthly GDT auction (GDT auction event dummy).

3. Methodology

3.1. Johansen's cointegration test

The cost-of-carry model of Kaldor (1939) defines the theoretical futures price at time t of a contract that matures at T, $F_{t,T}$, as a

[11] Roll-yield, also called basis, is the difference between the spot price of an asset and that of the corresponding futures contract at a particular point in time. A branch of the empirical finance literature measures the commodity futures roll-yield using the front-end contract price as proxy for the spot price. This approach is vindicated by the fact that the futures prices converge upon maturity to the spot price (see e.g., Fama and French, 1987; Gorton et al., 2013; Szymanowska et al., 2014). We follow this approach and consider the roll-yield as a futures market activity variable.

function of the time t spot price of the underlying commodity, S_t, and the net cost of carrying the spot asset, c_t which is measured as a rate. Mathematically, we have

$$F_{t,T} = S_t e^{c_t(T-t)} \tag{1}$$

or, after taking logarithms, $f_{t,T} = s_t + c_t(T-t)$. Estimating this relationship, we end up with

$$f_{t,T} = a + bs_t + z_t \tag{2}$$

where b defines the long-run relationship between s_t and $f_{t,T}$, where both have one unit root, $I(1)$, a depends on backwardation and contango as well as any market imperfections (Figuerola-Ferretti and Gonzalo, 2010), and z_t is an error term measured at time t.

The absence of arbitrage opportunity implies that there is a long-run equilibrium relationship between the nonstationary cointegrated series $f_{t,T}$ and s_t and thus, that the error correction vector, $z_t = f_{t,T} - bs_t - a$ with cointegrating vector $\beta = (1, -b)$, is stationary or $I(0)$. Namely, the two prices may diverge in the short run but, due to arbitrage and equilibrium pricing, they share a common component in the long run.[12]

To test for cointegration, we use the vector error correction model (VECM) of Johansen (1988).

$$\Delta p_t = \alpha(z_{t-1}) + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + e_t \tag{3}$$

where Δp_t is a 2×1 vector of spot and futures log returns $\Delta f_{t,T}$ and Δs_t at time t, α is a 2×1 vector that measures the speed of adjustment of the spot and futures prices back to their long-run equilibrium, the $2 \times k$ matrix Γ_i defines the short-run lead-lag relationship between the spot and futures return series, k is the lag order of the VAR process,[13] and e_t is a 2×1 vector of zero-mean serially-uncorrelated disturbances with covariance matrix Ω. The first term of the VECM, $\alpha(z_{t-1})$, captures the long-run equilibrium relationship between the two prices and the second term, $\sum_{i=1}^{k} \Gamma_i \Delta p_{t-i}$, models short-term variations around that equilibrium as driven by market imperfections.

We test two null hypotheses: *i*) the null hypothesis of no cointegration ($r = 0$) between s_t and $f_{t,T}$ against the alternative that there is one cointegrating vector ($r = 1$), and *ii*) the null hypothesis of one cointegrating vector or less ($r \leq 1$) against the alternative that there are two cointegrating vectors ($r = 2$). The tests are based on the trace and eigenvalue statistics. Rejection of the null hypothesis *i*) indicates the presence of cointegration, and rejection of the null hypothesis *ii*) indicates the presence of more than one cointegrating vector. A finding that s_t and $f_{t,T}$ are cointegrated means the two price series share (at least) one unobservable common factor called the implicit efficient price, m_t.

3.2. *Price discovery tests*

Measuring price discovery means measuring the contribution of each price series to the implicit efficient price, m_t. A finding that s_t contributes more than $f_{t,T}$ to m_t indicates price discovery predominantly takes place in the spot market. Two main approaches have been proposed: the component share (CS) of Gonzalo and Granger (1995) and the information share (IS) of Hasbrouck (1995).

3.2.1. *The component share of Gonzalo and Granger (1995)*

The common factor or implicit efficient price, m_t, is a combination of the price variables and thus, $m_t = \Gamma p_t$ where $p_t = \begin{pmatrix} s_t \\ f_{t,T} \end{pmatrix}$ and $\Gamma = (\gamma_s, \gamma_f)$ is a latent vector that defines the unobservable weights that m_t assigns to each price. Gonzalo and Granger (1995) define the contribution of a given market i to the common factor as a function of the error correction coefficients, α. Namely,

$$CS_f = \frac{|\alpha_s|}{|\alpha_s| + |\alpha_f|} \tag{4}$$

$$CS_s = \frac{|\alpha_f|}{|\alpha_s| + |\alpha_f|} \tag{5}$$

with, by construction, $CS_f + CS_s = 1$. The definition therefore implies an inverse relationship between *i*) the speed of price adjustment of a market back to the long-run cointegrating relationship or to the implicit efficient price, m_t (e.g., α_f) and *ii*) the component share of that market (e.g., CS_f). Intuitively, if $|\alpha_f| > |\alpha_s|$, the futures price has to put in more 'effort' than the spot price to reach the long-run equilibrium price and thus the spot market leads the price discovery process, which translates into a higher CS_s. Vice

[12] The price discovery literature (see e.g., Baillie et al., 2002) usually assumes $a = 0$ and $\beta = (1, -1)$, so that $z_t = f_{t,T} - s_t$. However, this provides misspecified error correction models when the true cointegrating vector differs (Figuerola-Ferretti and Gonzalo, 2010). In this paper, we study price discovery between the spot price and the futures prices of different maturity contracts, and hence, we do not impose the restriction $\beta = (1, -1)$ and $a = 0$. Instead, we leave the data to choose the error correction vector.

[13] We consider $k = 4$ and obtain qualitatively similar results with 2, 3 and 5 lags. These results are available from the authors upon request.

versa, a relatively larger $|\alpha_s|$ means the futures market plays a more important role than the spot market in bringing prices back to their long-run equilibrium relationship and thus, $CS_f > CS_s$.

3.2.2. The information share of Hasbrouck (1995)

Hasbrouck (1995) transforms the VECM of Equation (3) into the following vector moving average (VMA) representation

$$\Delta p_t = \Psi(L)e_t \tag{6}$$

where Ψ is a polynomial in the lag operator L. Under the Beveridge-Nelson decomposition, the price levels can be expressed as the initial prices p_0, a random component that is common to all prices, $\Psi(1)\sum_{s=1}^{t} e_s$, and a matrix polynomial in the lag operator, L, $\Psi^*(L) = \sum_{k=0}^{\infty}\Psi_k^*$ with $\Psi_k^* = -\sum_{j=k+1}^{\infty}\Psi_j^*$,

$$p_t = p_0 + \Psi(1)\sum_{s=1}^{t} e_s + \Psi^*(L)e_t, \tag{7}$$

where p_0 is a 2×1 vector of initial log prices, $\Psi(1)$ is a 2×2 impact matrix equal to the sum of the moving average coefficients, $\Psi(1) = \beta_\perp \psi$, with $\psi = \left(\alpha_\perp^{'}(I - \sum_{i=1}^{k}\Gamma_i)\beta_\perp\right)^{-1}\alpha_\perp^{'}$ the vector orthogonal to α representing the common row vector for the sum of the moving average matrices $\Psi(1)$, and $\beta_\perp$ and $\alpha_\perp$ are the orthogonal vectors of β and α, respectively, so that $\beta_\perp^{'}\beta_\perp = 0$ and $\alpha_\perp^{'}\alpha_\perp = 0$.

We decompose $\Psi(1)$ into $\beta_\perp\psi = \begin{pmatrix} \psi_s & \psi_f \\ \frac{\psi_s}{b} & \frac{\psi_f}{b} \end{pmatrix}$ where ψ is a vector with identical rows $(\psi_s \psi_f)$ and ψ_i is the contribution of market i to the efficient price m_t. The VMA then becomes

$$p_t = p_0 + \beta_\perp\psi\left(\sum_{s=1}^{t} e_s\right) + \Psi^*(L)e_t. \tag{8}$$

The time t log price can be seen as the sum of its initial value, a random permanent component that is common to all prices (or the implicit efficient price), and a stationary term, $\Psi^*(L)e_t$, that measures short-term transitory deviations of the actual price from the efficient price due to market imperfections. ψe_t denotes the time t innovation in the implicit efficient price.

The price discovery measure of Hasbrouck (1995), called information share, calculates each market contribution to the variance of the common factor innovations, i.e., $var(\psi e_t) = \psi\Omega\psi^{'}$. The market contributing the most to $var(\psi e_t)$ leads the price discovery process. If Ω is diagonal, the information share of e.g., the spot market, is defined as $IS_s = \frac{\psi_s^2\sigma_s^2}{\psi\Omega\psi^{'}}$. This relationship does not hold when Ω is non-diagonal, namely, in the presence of innovations that are significantly correlated. Then, Hasbrouck (1995) proposes to remove any contemporaneous residual correlation using the Cholesky decomposition of Ω with $\Omega = MM^{'}$ where M is a lower triangular matrix equal to $M = \begin{pmatrix} m_{ss} & 0 \\ m_{sf} & m_{ff} \end{pmatrix} = \begin{pmatrix} \sigma_1 & 0 \\ \rho\sigma_2 & \sigma_2(1-\rho^2)^{1/2} \end{pmatrix}$. The information shares of each market then become

$$IS_f = \frac{(\psi_f m_{ff})^2}{(\psi_s m_{ss} + \psi_f m_{sf})^2 + (\psi_f m_{ff})^2} \tag{9}$$

$$IS_s = \frac{(\psi_s m_{ss} + \psi_f m_{sf})^2}{(\psi_s m_{ss} + \psi_f m_{sf})^2 + (\psi_f m_{ff})^2}\ . \tag{10}$$

As the Cholesky decomposition is order sensitive (i.e., it gives more weight to the first component of p_t), the resulting measure depends on the ordering of the markets. Upper and lower bounds for the information share are calculated, switching the order of the spot and futures markets. Finally, the median of the upper and lower bounds for each market is what we report as the information share measure.

3.3. Panel regressions

We obtain time-varying measures of price discovery using rolling windows of 3-year twice-monthly observations. We see the 3-year window as a good trade-off between the noise of shorter windows and reducing the sample available by using longer widows.[14] The resulting time series can be used to test whether auction participation data facilitate price determination. In order to obtain a general conclusion across futures contracts and bearing the former point in mind, the following panel fixed effects regression is estimated,

[14] A much shorter window yields a noisy price discovery series that differs substantially from the full sample estimate. A much longer window reduces the sample available to study the drivers of price discovery. We see a 3-year window as providing a good trade-off. For instance, the full sample average of the 3-year CS-futures (IS-futures) series is 0.22 (0.16) which is very close to the full sample average reported in Table 5 of 0.17 (0.12).

$$PD_{f,n,t} = \theta_0 + \theta_P X_{n,t} + \upsilon_{n,t} \quad (11)$$

where $PD_{f,n,t}$ is the price discovery measure at time t for the futures market at maturity n (with $n = 1, \ldots, 6$) which is either $CS_{f,n,t}$ or $IS_{f,n,t}$, $X_{n,t}$ is a $P \times n$ matrix of explanatory variables observed at time t, θ_0 and θ_P are coefficients to estimate, and $\upsilon_{n,t}$ is a residual. To ease the interpretation of the coefficients, the X_t continuous variables are normalized to have a zero mean and standard deviation of one. As explanatory variables for price discovery, we consider the variables explained in Section 2.2 and Table 2 ($p = 1, \ldots, P$ with $P =$ 29). We also include contract fixed effects to control for any time-invariant heterogeneity in the maturities. We estimate Equation (11) by OLS and report its coefficients, White corrected t-statistics clustered by contract and week-year, and adjusted-R^2.

4. Empirical analysis

This section first studies price discovery in the WMP spot and futures markets and then analyzes whether auction market information plays a role in the price discovery process.

4.1. Are the spot and futures markets cointegrated?

As discussed in Section 2.1, we study price discovery with regards to the twice-monthly spot auction price and the corresponding 1^{st} to 6^{th} nearby futures contracts. For the spot and futures natural log prices to be cointegrated, we first need to ensure they are unit root nonstationary at the same level. We test for unit roots using the augmented Dickey-Fuller (ADF) test, whose null hypothesis is the series have Y unit roots versus the alternative that the series have Y-1 unit roots. Table 3 reports the results of the ADF tests for log prices both in levels and in first differences. As expected, both spot and futures log prices are unit root nonstationary, meaning that their first difference is stationary. We conclude the log prices have one unit root.

The absence of arbitrage opportunity implies that the $I(1)$ series $f_{t,T}$ and s_t are cointegrated as captured by the VECM specification of Equations (1)–(3). Table 4 presents the results of Johansen cointegration tests based on trace and eigenvalues statistics for the null hypotheses that *i*) the $f_{t,T}$ and s_t series are not cointegrated ($H_{01} : r = 0$) and *ii*) they have at least one cointegrated relationship ($H_{02} : r \leq 1$). The results systematically suggest the presence of one cointegrating vector. The conclusion holds irrespective of the maturity of the futures contract or the statistic considered (trace or eigenvalue).

4.2. Which market leads price discovery?

Given that the futures and spot price series are cointegrated, we can measure the component share and information share of each market and thereby study which market leads the price discovery process. For each combination of spot and futures prices, the left-hand side of Table 5 reports the estimated coefficients, $\{a, b\}$, of Equation (2) and Wald tests for the null hypothesis $a = 0$ and $b = 1$. The idea is to test whether the cointegrating vector we estimate coincides with $\beta = (1, -1)$, as is often assumed in the literature, and as obtained when $a = 0$ and $b = 1$. Over the sample from October 2010 to July 2018, the results show that imposing the usual restriction $a = 0$ and $\beta = (1, -1)$ provides mispecified cointegrating vectors, as the null hypothesis in the Wald test is strongly rejected in all the cases, except for the front-end futures contract. This justifies the use of free coefficients a and b.

The right-hand side of Table 5 reports the estimated coefficients, α, on the error correction term in Equation (3), the calculated

Table 3
Augmented dickey-fuller tests.

	Level		1st Difference		Level		1st Difference	
	ADF	p-value	ADF	p-value	ADF	p-value	ADF	p-value
	log(GDT price)				log(F_4)			
TC	−2.35	(0.42)	−10.47	(0.00)	−2.29	(0.45)	−12.27	(0.00)
C	−2.15	(0.23)	−10.50	(0.00)	−1.98	(0.31)	−12.30	(0.00)
NC	−0.21	(0.57)	−10.53	(0.00)	−0.25	(0.56)	−12.34	(0.00)
	log(F_1)				log(F_5)			
TC	−2.12	(0.53)	−11.79	(0.00)	−2.41	(0.39)	−12.52	(0.00)
C	−1.93	(0.33)	−11.83	(0.00)	−2.06	(0.27)	−12.56	(0.00)
NC	−0.26	(0.55)	−11.86	(0.00)	−0.25	(0.56)	−12.59	(0.00)
	log(F_2)				log(F_6)			
TC	−2.60	(0.30)	−11.45	(0.00)	−2.46	(0.37)	−12.28	(0.00)
C	−1.99	(0.30)	−11.48	(0.00)	−2.14	(0.24)	−12.31	(0.00)
NC	−0.28	(0.55)	−11.51	(0.00)	−0.28	(0.55)	−12.34	(0.00)
	log(F_3)							
TC	−2.25	(0.47)	−12.02	(0.00)				
C	−1.99	(0.30)	−12.06	(0.00)				
NC	−0.27	(0.55)	−12.09	(0.00)				

The table reports results of Augmented Dickey-Fuller tests for the spot price and the 1st to the 6th nearby WMP futures prices in levels and first differences. TC denotes the presence of a deterministic trend and a constant, C denotes the presence of a constant, NC denotes the absence of both. F_n designates the futures price with the n^{th} maturity. The sample covers the period from October 2010 to July 2018.

Table 4
Johansen cointegration test.

	H_{01}: r = 0		H_{02}: r ≤ 1	
	Trace	Eigenvalue	Trace	Eigenvalue
Spot vs. F_1	27.85	23.12	4.73	4.73
	(0.00)	(0.00)	(0.37)	(0.37)
Spot vs. F_2	27.57	22.40	5.17	5.17
	(0.00)	(0.00)	(0.31)	(0.31)
Spot vs. F_3	21.16	15.86	5.30	5.30
	(0.04)	(0.05)	(0.29)	(0.29)
Spot vs. F_4	22.41	17.12	5.30	5.30
	(0.02)	(0.03)	(0.29)	(0.29)
Spot vs. F_5	21.65	16.53	5.12	5.12
	(0.03)	(0.04)	(0.31)	(0.31)
Spot vs. F_6	21.25	15.57	5.68	5.68
	(0.04)	(0.06)	(0.23)	(0.23)

The table reports the results of the Johansen cointegration test based on trace and eigenvalues statistics. The null hypothesis is non-cointegration ($H_{01}: r = 0$) and at least one cointegration relationship ($H_{02}: r \leq 1$). *p*-values are in parentheses. F_n designates the futures price with the n^{th} maturity. The sample covers the period from October 2010 to July 2018.

Table 5
Measures of price discovery.

	a	*b*	Wald test		*α*				Component Share		Information Share	
			(H_0: a = 0, b = 1)		Spot		Futures		Spot	Futures	Spot	Futures
Spot vs. F_1	−0.1364	1.0161	4.56	{0.10}	−0.0046	(-0.02)	0.6118	(3.47)	0.99	0.01	0.95	0.05
Spot vs. F_2	−0.8143	1.0979	55.11	{0.00}	−0.0655	(-0.59)	0.4231	(2.93)	0.87	0.13	0.88	0.12
Spot vs. F_3	−1.4621	1.1768	72.11	{0.00}	−0.0711	(-0.78)	0.2643	(2.34)	0.79	0.21	0.83	0.17
Spot vs. F_4	−2.0702	1.2508	79.67	{0.00}	−0.0690	(-0.85)	0.2092	(2.61)	0.75	0.25	0.82	0.18
Spot vs. F_5	−2.4689	1.2992	87.68	{0.00}	−0.0673	(-0.92)	0.1894	(2.72)	0.74	0.26	0.85	0.15
Spot vs. F_6	−2.6865	1.3258	71.20	{0.00}	−0.0275	(-0.45)	0.1833	(3.19)	0.87	0.13	0.96	0.04
Average	−1.6064	1.1944			−0.0508		0.3135		0.83	0.17	0.88	0.12

The table presents the coefficients {*a, b*} of Equation (2), the result of a Wald test for the null hypothesis $a = 0$ and $b = 1$ in curly brackets, the speed of adjustment *α* and its Newey-West corrected *t*-statistic in parentheses, the component share of Gonzalo and Granger (1995) and the information share of Hasbrouck (1995). F_n designates the futures price with the n^{th} maturity. Boldface font denotes the market dominating price discovery. The sample covers the period from October 2010 to July 2018.

component shares of Equations (4) and (5) and the calculated information shares of Equations (9) and (10). Across futures maturities, the component share of the spot market (CS_s) averages 0.83, with a range 0.74 from to 0.99. The information share of the spot market (IS_s) averages 0.88, with a range from 0.82 to 0.96. This indicates that WMP price discovery takes place predominantly in the spot market. Aligned with this conclusion, we note that α_f is positive at the 5% level or better and α_s is zero in statistical terms. The fact that $|\alpha_f| > |\alpha_s|$ suggests that the futures price needs to change quite substantially to catch up with the spot price. Since the average IS_s at 0.88 is close to the average CS_s at 0.83, allowing for contemporaneous cross-correlation in the VECM residuals does not seem to alter the conclusion on the superior price discovery of the spot market (Baillie et al., 2002). Our results, that the discovery of WMP prices takes place in the spot market, corroborates evidence previously presented in other commodity markets by e.g., Dolatabadi et al. (2015), Dimpfl et al. (2017) and Narayan and Sharma (2018).

We attribute the dominance of the spot market in terms of price discovery to three reasons. First, the creation of the GDT platform predates the inception of the first futures contract (as detailed in Section 2.1). Second, over the period from October 2010 to July 2018, the average volume of WMP traded at the auction (7466 metric tons) is 2.3 times higher than the average volume traded on the futures curve (3233 metric tons, as summarized in Table 1), suggesting the spot market is preeminent. Third, relative trading costs may be another explanation of why the spot market dominates in terms of price discovery. Bidders do not pay participation fees in the GDT auction (Rule C1.13 in the GDT Trading Event Rules, August 2022). However, assuming a range of trading costs between 30USD and 70USD per roundtrip as in Fernandez-Perez et al. (2022) and dividing this amount by the average NZX WMP futures prices in Table 1, the cost of trading WMP futures ranges between 0.88% and 2.10%. To put this into perspective, the roundtrip transaction cost for US commodity futures is 0.086% (Marshall et al., 2012). These findings highlight the substantial trading costs incurred by the WMP futures traders in comparison with the GDT traders.

Fig. 4 plots both the estimated CS_f and IS_f figures obtained over the whole sample (as reported in Table 5) as well as the time dynamics of the $CS_{f,t}$ and $IS_{f,t}$ measures obtained using rolling windows of 3 years or 72 twice-monthly observations. For brevity, the plot pertains to second-end WMP futures only but similar results were obtained when using other maturity contracts. The figure shows

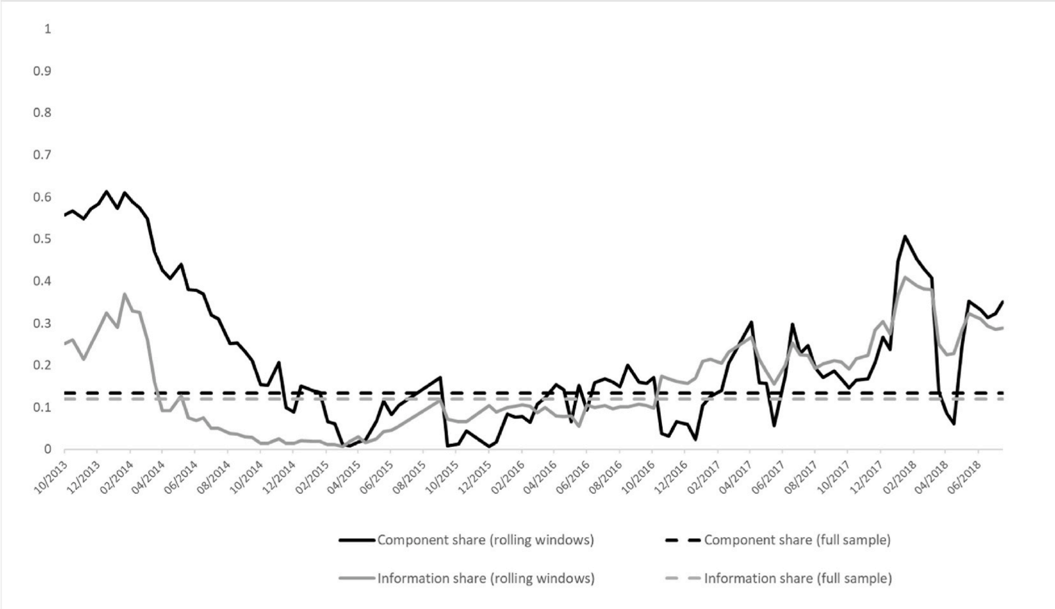

Fig. 4. Price discovery for second-end WMP futures contracts.

that the averages of $CS_{f,t}$ and $IS_{f,t}$ over time match the estimates of CS_f and IS_f obtained in Table 5. With the possible exception of the $CS_{f,t}$ results at the beginning of the sample period, the dominance of the spot market in the price formation process is not challenged over time: WMP price discovery takes place in the spot market both over time and on average.

We note, however, some variations over time with both price discovery measures rising above their full sample estimates at the beginning and at the end of the sample period, and falling below their full sample estimates in the middle of our sample. The correlation between $CS_{f,t}$ and $IS_{f,t}$ equals 0.61 (*t*-statistic of 7.96) suggesting some commonalities between the two price discovery measures and thus possibly the presence of common factors that could explain their dynamics. The next section deals with this point.

4.3. Determinants of price discovery in the WMP futures market

This section studies the determinants of price discovery dynamics in the WMP futures market. To do so, we estimate the panel fixed effects regression of Equation (11) using the time-dependent price discovery measure of the futures market as our dependent variable; namely, either $CS_{f,t}$ or $IS_{f,t}$. The determinants of price discovery; namely, the independent variables of Equation (11), are measured as detailed in Table 2. Table 6 reports the OLS estimates, White corrected *t*-statistics clustered by contract and week-year, adjusted-R^2 of the regression, as well as the difference in adjusted-R^2 between a model including the auction data and another model excluding them. The price discovery measures are CS_f on the left-hand side and IS_f on the right-hand side of Table 6. The estimation of the first price discovery measure necessitates 72 twice-monthly observations and thus, the sample used in Table 6 covers the period from October 2013 to July 2018 for a total of 648 twice-monthly-contract observations.

The determinants of price discovery explain its dynamics well with an average adjusted-R^2 of 0.62 in Table 6. Focusing on the variables that are significant across price discovery measures, we note that the information coming from bidders' participation (namely, the total volume bought by winning bidders in Panel A) is a strong determinant of price discovery; it also presents one of the largest coefficients, both economically and statistically. Specifically, a larger volume bought by winning bidders across all dairy products (and not only WMP) implies better transmission of information to the futures market and an increase in its price discovery. Confirming the importance of bidder participation, we note that adding spot auction data to Equation (11) increases the adjusted-R^2 of the model by an average of 5%.

We hypothesize the following mechanism as a rationale for our finding that a rise in the total volume bought by winning bidders enhances the price discovery of the futures market. GDT bidders have access to the dairy volume offered in the GDT auction (or dairy supply) well in advance of the start of the auction (Rules C2.10 and C2.11 in the GDT Trading Event Rules, August 2022). With this information at hand, during weeks when the dairy supply increases, and accordingly, the volume of winning bidders rises, spot prices tend to drop, potentially pushing rational speculators to take shorter futures positions than they would otherwise. Likewise, it could then be rational for dairy producers (consumers) with advanced information about an increase of the dairy supply before the GDT auction to engage in selective hedging by taking shorter (less long) futures positions than those implied by pure risk minimizing motives. In other words, a rise in the volume of winning bidders could induce a change in the strategies that futures market participants follow, thereby raising the price discovery of the futures market. Unfortunately, we do not have data on participant positions in the NZX futures market, so we cannot test empirically whether speculators and hedgers alter their futures positions when the volume

Table 6
Determinants of price discovery.

	Component Share		Information Share	
Panel A: GDT auction data				
WMP-specific auction				
Actual volume of WMP sold	−0.025	(-1.16)	−0.015	(-0.97)
Level of auction under-subscription	0.022	(2.32)	0.006	(0.91)
Overall non WMP-specific GDT auction				
Total volume bought by winning bidders	0.171	(3.70)	0.072	(3.13)
Change in number of qualified bidders	−0.006	(-1.15)	−0.004	(-1.12)
Number of winning bidders	0.005	(0.41)	−0.002	(-0.22)
Number of bidding rounds	0.025	(0.78)	0.018	(0.88)
Duration of trading event	−0.008	(-0.29)	−0.008	(-0.45)
Panel B: Futures market activity				
Roll-yield	0.013	(1.34)	0.007	(1.18)
Liquidity (%zeros)	0.004	(0.88)	0.001	(0.23)
Liquidity (Amihud)	−0.003	(-0.53)	−0.002	(-0.72)
Skewness	0.028	(1.49)	0.029	(2.19)
Volatility	0.003	(0.28)	−0.001	(-0.17)
Volume	0.004	(0.35)	0.000	(-0.06)
Panel C: Milk market pricing and sentiment				
Milk market price	0.081	(6.21)	0.035	(4.38)
Milk market risk	−0.014	(-1.79)	−0.011	(-1.87)
Sentiment	0.029	(1.05)	0.022	(1.46)
Panel D: Seasonality and trend				
Jan	0.134	(2.61)	0.063	(2.42)
Feb	0.178	(3.37)	0.067	(2.62)
Mar	0.143	(3.15)	0.028	(1.00)
Apr	0.109	(2.19)	−0.006	(-0.23)
May	0.147	(4.18)	−0.013	(-0.58)
Jun	0.113	(2.58)	−0.026	(-0.82)
Jul	−0.004	(-0.08)	−0.072	(-2.75)
Aug	−0.107	(-3.04)	−0.099	(-4.69)
Sep	−0.133	(-3.42)	−0.085	(-3.70)
Oct	−0.128	(-3.33)	−0.082	(-4.23)
Nov	−0.097	(-3.90)	−0.054	(-3.97)
Trend	0.003	(2.31)	0.003	(8.20)
GDT event dummy	0.026	(1.73)	0.007	(0.82)
Fixed effects	YES		YES	
Adj-R^2	0.580		0.653	
ΔAdj-R^2	0.077		0.023	
Number of observations	648		648	

The table reports the panel fixed effects regression results of Equation (11) for the price discovery dynamics, based on 3-year twice-monthly rolling windows. The models include an unreported constant and contract fixed effects. White corrected *t*-statistics clustered by contract and week-year are reported in parentheses. ΔAdj-R^2 measures the difference in adjusted-R^2 between the full model and a restricted version without GDT auction data (Panel A). The sample covers the period from October 2013 to July 2018.

bought by winning bidders across all dairy products changes.

Interestingly, while volume data coming from the *spot* market explain the price discovery of the *futures* market (Panel A), characteristics of the *futures* market do not, with the exception of futures skewness for the information share (Panel B). Moreover, we note the importance of the spot price of milk products and its volatility (Panel C) in explaining price discovery which serves to substantiate the importance of spot market information further. Bringing the evidence of Tables 5 and 6 together, it appears price discovery takes place in the spot market and is mainly driven by spot market information.

Finally, we observe a strong seasonality in the price discovery of the WMP futures market; it increases in summer months in the southern hemisphere (January and February) and decreases in winter and spring months (August to November). This seasonality coincides with the seasonality in New Zealand milk production, which is lower in summer months and higher in winter months, and suggests that the WMP futures (spot) market is relatively more (less) informative in periods of low milk production. Finally, while the CS and IS measures of Table 5 and Fig. 4 invariably suggest the spot market dominates price discovery, we note a tendency for price discovery to slowly switch to futures markets – demonstrated by the positive and highly significant coefficient on the trend variable, after controlling for bidder participation, futures and spot market information, and seasonalities. We attribute this to market participants becoming increasingly acquainted with the workings of the WMP futures market.

4.4. Robustness

In this section, we check the robustness of our results for periods of high versus low volatility in the volume sold and for the timing of the futures prices.

4.4.1. High versus low volatility periods

Comparing Figs. 1 and 4, it seems that the price discovery of the futures market rises with the volatility of the volume of WMP sold at the auction. This motivates the addition of the volatility of the volume of WMP sold as a control variable in the panel regressions of Table 6, where the volatility is measured as the standard deviation of the actual volume of WMP sold over a fixed window of 12 twice-monthly observations. Table 7, Panel A presents the estimated slope coefficients of the regressions for the auction data, alongside White corrected *t*-statistics clustered by contract and week-year over the sample period spanning October 2013 to July 2018. The slope coefficient on the volatility of actual volume of WMP sold equals 0.031 (*t*-statistic of 2.43) for CS and 0.011 (*t*-statistic of 1.63) for IS. This suggests that in periods of high uncertainty about the volume of WMP sold in the auction, investors tend to hedge more, incorporating more information in the futures market, and therefore, increasing its price discovery.[15] We also divide the sample into periods of high or low volatility of the volume of WMP sold, using the series full sample average as a breakpoint. The results reported in Table 7, Panels B and C indicate that the coefficients on the total volume bought by winning bidders remain positive and significant at the 5% level or better. Adding GDT bidder participation to the price discovery models increases the adjusted-R^2 of the regressions by an average of 5% across Panels A to C. These results confirm our earlier inferences regarding the role played by auction data.

4.4.2. Futures prices collection timing

Our baseline results thus far match the auction prices obtained at the beginning of day *t* with the futures settlement prices at the close of day *t*-1. Before the auction event begins, futures market participants have access to the minimum supply, maximum supply, and starting price for each dairy product and contract period that sellers will offer at the auction (Rules C2.10 and C2.11 in the GDT Trading Event Rules, August 2022). Given the very low percentage of unsold volume in the auctions (on average 0.18% of the amount offered was not sold in our sample), the amount offered is usually the same as the amount actually sold during the auction. Therefore, the information regarding the volume of dairy products that may be sold is widely available to all the participants in the futures markets *before* the auction starts.

However, investors can only access auction specific information such as the number of winning bidders or the duration of the auction *after* the auction; that information is disclosed on the day the auction takes place (day *t* in Fig. 2). It is therefore legitimate to wonder whether the availability (or lack thereof) of auction data influences our baseline results. To address this potential caveat, we match the auction prices obtained at day *t* with the futures settlement prices at the close of the same day. Doing this, we allow futures market participants to have access to the results of the auction. The results, reported in Table 8, show that the slope coefficients on the total volume bought by winning bidders equal 0.193 (*t*-statistic of 3.56) for CS and 0.053 (*t*-statistic of 2.33) for IS, and that adding GDT bidder participation to the price discovery models increases the adjusted-R^2 of the panel regressions by an average of 7%. These results suggest that the timing of the futures data collection does not alter the main conclusion of the paper.[16]

4.5. Global demand as a driver of price discovery in the New Zealand futures market

Our results demonstrate that the total volume bought by winning bidders is a key determinant of price discovery in the futures market. The available data enable us to go a step further and determine whether some categories of bidders influence New Zealand price discovery more than others. To do that, we split the total volume bought by winning bidders across several regions: Africa, Europe, the Middle East, North America, North Asia (i.e., China), South and Central America, as well as South East Asia and Oceania. The results reported in Table 9 indicate a strong influence of the volumes of trading coming from North America (*t*-statistics of 3.65 and 3.99 for CS and IS, respectively), Africa (*t*-statistics of 4.53 and 4.76), and North Asia (*t*-statistics of 3.53 and 4.30), whose rise in demand increases the price discovery of the futures market. Our results suggest that the volume bought may be acting as a proxy for the level of activity in a particular buyer group; there is indeed a comparatively larger number of bidders in the North Asian group. Interestingly, the price discovery of the futures market decreases in periods of higher volume bought by European bidders (*t*-statistics of −3.34 and −3.15). We interpret this result as European bidders incorporating their information in the spot market, rather than the futures market.

Altogether, the results presented in Table 9 serve as indirect evidence of the magnitude and significance of the demand coming from North America, Africa, and North Asia in determining the New Zealand price of dairy products and thus corroborate the importance of New Zealand as a global player in the dairy trade. This conclusion is also consistent with New Zealand being the world's largest producer of WMP, representing 56% of global exports between 2018 and 2020 and accounting for 32% of world dairy exports (OECD-FAO Agricultural Outlook 2021–2030, 2021).

5. Conclusions

Our paper is the first to study whether auction-level data from the spot market, such as the volume of a physical commodity bought

[15] We obtain similar results when we measure the volatility of the volume of WMP sold as the standard deviation of the actual volume of WMP sold over a fixed window of 24 twice-monthly observations or when we create a dummy equal to one in periods of volatility higher than its 80% percentile.

[16] Likewise, we test whether the inference on the superior price discovery of the spot market (Table 5) depends on the consideration of the day *t* (in place of *t*-1) settlement futures prices. Results show that the CS and IS measures do not depend on the chosen date for the futures price; they are available upon request.

Table 7
Determinants of price discovery in periods of high versus low volatility in the volume of WMP sold.

	Panel A: Full sample analysis				Panel B: Low volatility periods				Panel C: High volatility periods			
	Component Share		Information Share		Component Share		Information Share		Component Share		Information Share	
WMP-specific auction												
Actual volume of WMP sold	−0.011	(-0.51)	−0.010	(-0.63)	−0.021	(-0.71)	−0.023	(-1.19)	−0.037	(-2.30)	−0.010	(-0.73)
Level of auction under-subscription	0.023	(2.52)	0.007	(0.95)	0.023	(1.50)	0.007	(0.67)	0.018	(1.40)	0.003	(0.45)
Volatility of volume of WMP sold	0.031	(2.43)	0.011	(1.63)								
Overall non WMP-specific GDT auction												
Total volume bought by winning bidders	0.161	(3.46)	0.068	(2.91)	0.143	(2.06)	0.062	(2.00)	0.190	(3.75)	0.057	(2.13)
Change in number of qualified bidders	−0.005	(-1.18)	−0.003	(-1.11)	−0.025	(-2.42)	−0.014	(-2.16)	−0.003	(-0.56)	−0.001	(-0.38)
Number of winning bidders	0.013	(1.00)	0.001	(0.10)	0.036	(1.66)	0.012	(1.06)	−0.034	(-1.71)	−0.016	(-2.21)
Number of bidding rounds	0.046	(1.85)	0.025	(1.34)	0.080	(2.09)	0.033	(1.29)	−0.058	(-2.01)	−0.029	(-1.69)
Duration of trading event	−0.030	(-1.25)	−0.016	(-0.90)	−0.073	(-2.14)	−0.028	(-1.21)	0.049	(1.82)	0.024	(1.46)
Controls	YES		YES		YES		YES		YES		YES	
Fixed effects	YES		YES		YES		YES		YES		YES	
Adj-R^2	0.589		0.655		0.614		0.665		0.648		0.691	
ΔAdj-R^2	0.086		0.025		0.083		0.032		0.065		0.010	
Number of observations	648		648		378		378		270		270	

Panel A adds the volatility of the volume of WMP sold (measured as the standard deviation of the actual volume of WMP sold over a fixed window of 12 twice-monthly observations) to the determinants of price discovery considered in Table 6. Panels B and C consider periods of low versus high volatility of the volume of WMP sold, using the full sample average volatility as a breakpoint. The table presents the coefficients on the GDT auction data but the models also include a constant, controls (futures market activity, milk market pricing and sentiment, seasonality and trend), and contract fixed effects. White corrected *t*-statistics clustered by contract and week-year are reported in parentheses. ΔAdj-R^2 measures the difference in adjusted-R^2 between the full model and a restricted version without GDT auction data. The full sample covers the period from October 2013 to July 2018.

Table 8
Determinants of price discovery: Sensitivity analysis of data collection timing.

	Component Share		Information Share	
WMP-specific auction				
Actual volume of WMP sold	−0.046	(-1.24)	−0.011	(-0.75)
Level of auction under-subscription	0.014	(1.34)	0.003	(0.44)
Overall non WMP-specific GDT auction				
Total volume bought by winning bidders	0.193	(3.56)	0.053	(2.33)
Change in number of qualified bidders	−0.007	(-1.27)	−0.006	(-1.79)
Number of winning bidders	−0.007	(-0.49)	0.001	(0.19)
Number of bidding rounds	−0.025	(-0.72)	−0.015	(-0.94)
Duration of trading event	0.035	(1.12)	0.016	(1.05)
Controls	YES		YES	
Fixed effects	YES		YES	
Adj-R^2	0.507		0.774	
ΔAdj-R^2	0.004		0.145	
Number of observations	648		648	

The table illustrates the sensitivity of the price discovery results to the data collection timing for the futures and spot prices; both are now measured on the day of the auction. The table presents the coefficients on the GDT auction data but the models also include a constant, controls (futures market activity, milk market pricing and sentiment, seasonality, and trend), as well as contract fixed effects. White corrected *t*-statistics clustered by contract and week-year are reported in parentheses. ΔAdj-R^2 measures the difference in adjusted-R^2 between the full model and a restricted version without GDT auction data. The sample covers the period from October 2013 to July 2018.

Table 9
Regional analysis.

	Component Share		Information Share	
WMP-specific auction				
Actual volume of WMP sold	0.004	(0.23)	−0.015	(-1.30)
Level of auction under-subscription	0.021	(2.49)	0.004	(0.75)
Overall non WMP-specific GDT auction				
Total volume bought by winning bidders				
African bidders	0.050	(4.53)	0.029	(4.76)
European bidders	−0.028	(-3.34)	−0.017	(-3.15)
Middle Eastern bidders	0.038	(1.50)	0.021	(2.06)
North American bidders	0.031	(3.65)	0.021	(3.99)
North Asian bidders	0.076	(3.53)	0.049	(4.30)
South & Central American bidders	0.017	(1.90)	0.008	(1.65)
South East Asian & Oceania bidders	0.033	(1.69)	0.015	(1.81)
Change in number of qualified bidders	0.001	(0.19)	0.003	(0.79)
Number of winning bidders	−0.001	(-0.05)	−0.009	(-1.36)
Number of bidding rounds	0.000	(-0.01)	0.005	(0.31)
Duration of trading event	0.013	(0.49)	0.002	(0.11)
Controls	YES		YES	
Fixed effects	YES		YES	
Adj-R^2	0.608		0.693	
ΔAdj-R^2	0.105		0.064	
Number of observations	648		648	

This table studies the determinants of price discovery after disaggregating the total volume brought by winning bidders across regions. The table presents the coefficients on the GDT auction data but the models also include a constant, controls (futures market activity, milk market pricing and sentiment, seasonality and trend), as well as contract fixed effects. White corrected *t*-statistics clustered by contract and week-year are reported in parentheses. ΔAdj-R^2 measures the difference in adjusted-R^2 between the full model and a restricted version without GDT auction data (Panel A). The sample covers the period from October 2013 to July 2018.

or sold at the auction, impact the discovery process between the spot and futures prices. These direct measures of supply and demand are key determinants of price and thus natural candidates for inclusion into the set of factors that could explain the price discovery dynamics between the spot and futures markets.

Making use of a unique dataset of auction-level variables pertaining to New Zealand's dairy spot market, we show that the information coming from the auction data contributes to the price discovery in the whole milk powder futures market, adding 6% explanatory power on average across model specifications. In particular, a larger volume bought by winning bidders across all dairy products implies better transmission of information to the futures market suggesting that it induces a change in the strategies that futures market participants follow. On the other hand, futures market characteristics do not enhance price discovery in the futures market, again corroborating the importance of the spot market information in terms of price discovery. Due to lower transaction costs and higher trading volume, the spot market is found to dominate the price discovery process. The leading role of the spot market could also be the outcome of the earlier inception of the auction market relative to the futures market.

Given that New Zealand represents roughly a third of global dairy trade and given that its exports of whole milk powder represent 56% of total global exports, these results are relevant to both local and international participants in the dairy spot and futures markets, from farmers and dairy processors to food manufacturers and traders. An important limitation of our study is that the auction data only allows us to examine the New Zealand dairy market. We see the analysis of other commodity markets as interesting avenues for future research, pending data availability.

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CRediT authorship contribution statement

Adrian Fernandez-Perez: Conceptualization, Software, Writing- Reviewing and Editing. **Joëlle Miffre:** Conceptualization, Writing- Original draft preparation, Writing- Reviewing and Editing. **Tilman Schoen:** Conceptualization, Data curation, Writing- Original draft preparation, Methodology, Software. **Ayesha Scott:** Conceptualization, Writing- Original draft preparation, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Currently, Associate Editor of Journal of Commodity Markets.

Data availability

The data that has been used is confidential.

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Appendix A. The New Zealand dairy market

The appendix positions New Zealand as a key player in the global dairy trade. It also provides supplementary background information on the New Zealand dairy market and further specifics on WMP traded on the GDT platform. The portfolio of products offered by sellers on GDT includes various dairy products, including whole milk powder, skim milk powder, anhydrous milk powder, butter, buttermilk powder, cheddar, lactose, rennet casein, and sweet whey powder.

The New Zealand dairy market represents a sizeable proportion (roughly a third) of the volume of dairy products traded worldwide. During 2017, New Zealand exported 1,330,000 metric tons (Mt) of whole milk powder, 400,000 Mt of skim milk powder, and 173,000 Mt of anhydrous milk powder (Trade Map, 2018). These figures make New Zealand the world's largest producer of WMP, representing 56% of the global WMP exports (OECD-FAO Agricultural Outlook 2021–2030, 2021). Figure A1 displays the exports of dairy products (in Mt) by region. As an aside, New Zealand is also the world's largest exporter of butter, representing 43% of global exports in 2018–2020 (OECD-FAO Agricultural Outlook 2021–2030, 2021). Further, New Zealand-based Fonterra (a farmers' cooperative representing around 80% of New Zealand's milk production and the largest seller at the GDT auction) is the world's biggest dairy exporter, representing nearly a third of global dairy trade (Brockett, 23 June 2022). For these reasons, it is unsurprising that New Zealand and its dairy market, especially the GDT auction, play a leading role in setting dairy prices worldwide (Stein, 2022).

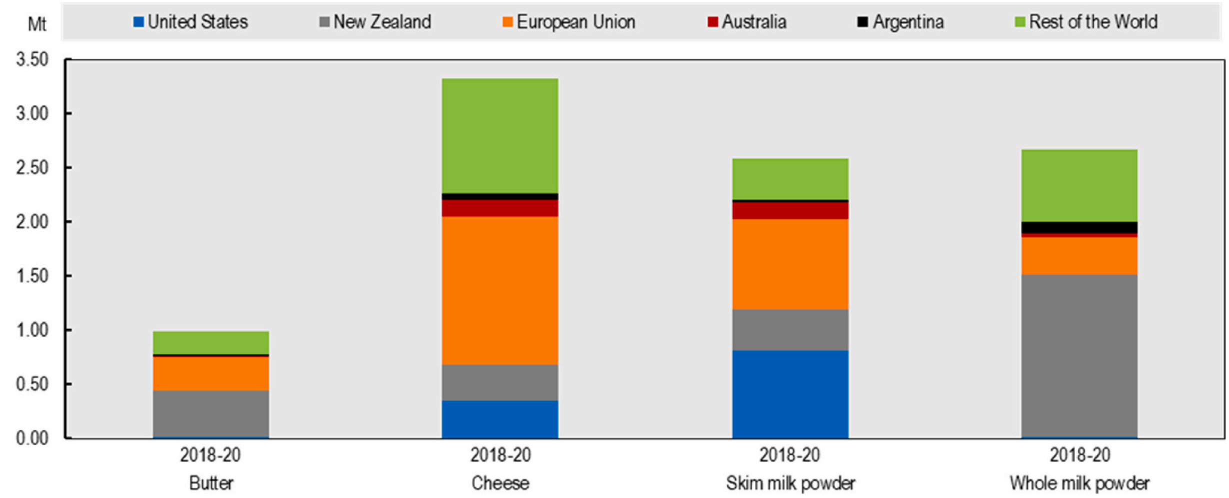

Fig. A1. Exports of dairy products (in metric tons) by region
Source: OECD-FAO. 2021. "OECD-FAO Agricultural Outlook OECD Agriculture statistics (database)", https://doi.org/10.1787/agr-outl-data-en

Additionally, the European Union, the US, and New Zealand jointly represented 70% of global dairy exports between 2018 and 2020 (OECD-FAO Agricultural Outlook 2021–2030, 2021). Figure A2 presents the percentages of total dairy volume that each region bought, averaged over the sample period, representing the geographical origins of the winning bidders at the GDT auction. The diversity of bidder origins is evident, with a sizeable proportion of total volume (77%) coming from bidders located outside South-East Asia and Oceania. For example, North Asian bidders bought on average 47% of the total volume traded at the auction, Middle Eastern and African bidders represent 12% and 8% respectively, and the remainder is split amongst European and American bidders. The relatively weaker percentages of Europe and North America in terms of volume bought highlight the fact that these regions, together with New Zealand, are major exporters of dairy products.

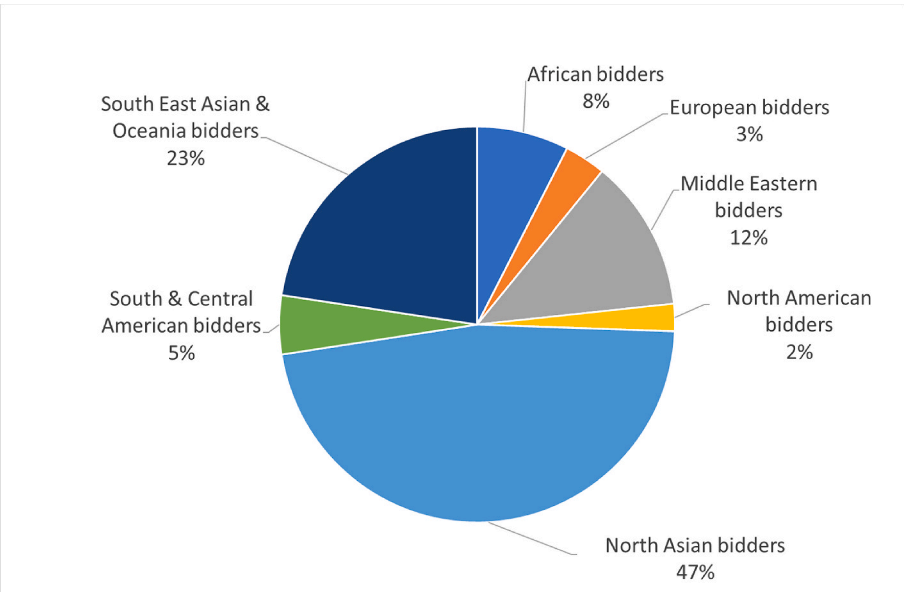

Fig. A2. Geographical Origin of Winning Bidders (October 2010–July 2018)

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