Price and Quantity Discovery without Commitment[*]

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Abstract

Wholesale electricity markets solve a complex allocation problem: electricity is not storable, demand is uncertain, and production involves dynamic cost considerations and indivisibilities. The New Zealand wholesale electricity market attempts to solve this complex allocation problem by using an indicative price and quantity discovery mechanism that ends at dispatch. Can such a market mechanism without commitment provide useful information? We document that indicative prices and quantities are increasingly informative of the final prices and quantities and that those bid revisions are consistent with information-based updating. We argue that the reason why the predispatch market is informative despite the lack of commitment is that it generates private benefits in terms of improved intertemporal optimization of production plans.

KEYWORDS: electricity markets, price discovery, pre-play communication, non-trading mechanisms, coordination, intertemporal optimization.

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1 Introduction

Markets and prices play an important coordinating role in our economies. They direct producers where there is demand, help consumers optimize, and, more generally, foster efficient allocation of resources. This coordination role is especially crucial in wholesale electricity markets where demand and supply are uncertain and largely inelastic in the short run, and yet, because electricity is difficult to store, demand and supply must be balanced at all times to avoid system outages.

Existing electricity markets typically solve this problem by organising a sequence of markets (typically week-ahead, day-ahead, and real-time) to coordinate supply and demand. The markets gradually lock in demand and supply and reduce uncertainty for market participants. New Zealand is an exception. The market is only called once, and all physical allocation decisions are based on bids submitted one hour prior to dispatch. To nevertheless help market participants coordinate supply and demand, the New Zealand electricity system operator organises a series of indicative markets (called predispatch) starting 36 hours before dispatch where participants can submit and update bids freely, and indicative prices and quantities are produced on a regular basis. Only the last bids submitted are used for the final allocation.

Can markets without commitment, such as the New Zealand electricity market, foster efficient price and quantity discovery? We examine bidding behaviour and bid revisions in the predispatch market. Our data spans 4 years and over 80,000 trading periods, each with a predispatch market called 24 times before actual dispatch. We observe individual market participants' bids and revisions, indicative prices and quantities during predispatch, and final allocations.

We provide evidence that indicative prices and quantities are increasingly informative of final prices and quantities and that bid revisions are consistent with information-based updating. On average, 3% of generation is reallocated during predispatch as a result of these bid revisions. Prices increase very slightly (less than 1%) and become less volatile over the course of the predispatch. We provide suggestive evidence that the predispatch market facilitates generation coordination across trading periods and therefore acts as a complement to the otherwise static (single period) allocation decisions produced by the New Zealand electricity market model.

The New Zealand predispatch market is an example of what is called an iterative mechanism, a market organisation that allows participants to update their bids based on feedback about the ongoing price before allocations are finalized. Iterative mechanisms are credited with at least three advantages. First, iterative mechanisms facilitate and support participants' decision-making. Decisions typically take the form of whether to stay in or drop-out or adjust a bid at the margin, and participants receive direct feedback on how their choices impact their allocation.

Second, iterative mechanisms elicit and aggregate information, which can foster competition. This is the famous "linkage principle" first identified by Milgrom and Weber (1982) and generalized to multi-unit auctions by Ausubel (2004). The insight here is that iterative mechanisms generate information that helps participants update their estimates of costs or value and protect them from the winner's curse, a phenomenon that typically holds back aggressive bidding.

A third advantage of iterative mechanisms is that they help market participants optimize their allocation when the bidding language is not rich enough to capture underlying costs and preferences. Nisan and Segal (2006) have characterized the communication requirements of efficient allocations in the presence of nonconvex preferences and indivisible goods. In electricity markets, these correspond to fixed start-up costs, ramp-up and ramp-down production constraints, and unit commitment (see e.g. Reguant (2014) for evidence). Nisan and Segal (2006) show that the number of prices needed, and therefore the complexity of the required bidding language, grows exponentially with the relevant states of the world. Iterative mechanisms, which run parallel markets for commodities that are related from the participants' perspective, partially overcome this curse of dimensionality (Ausubel and Cramton, 2004). They have been used, for example, by EDF to auction generation capacity in France and by the US Federal Communication Commission to auction spectrum.

Participants in electricity markets are typically sophisticated and well-informed. Moreover, the level of market transparency in New Zealand is particularly high. So the first two advantages of iterative mechanisms we have described are unlikely to be first order in the context of the New Zealand electricity market. In contrast, Nisan and Segal (2006)'s findings imply, in particular, that market participants in electricity markets should be able to condition their allocation in one trading period on their allocation in some other trading periods, something that the New Zealand market model does not allow. This provides a rationale for an iterative mechanism such as the predispatch.

To support genuine price discovery, iterative mechanisms often include an activity rule designed to curb manipulative bids. Participants can revise their bids but cannot make a "worse" offer (where what "worse" means depends on the specific context). Alternatively, some mechanisms include a random end-time that ensures that bidders are committed to their bids. What's remarkable about the New Zealand predispatch market is that it does not contain any such form of commitment.[1] This means that bids during the predispatch can be seen as "cheap talk".

Another example of iterative mechanisms without commitment are preopening periods at stock exchanges. During preopening, traders submit and freely revise their offers during a certain period, until the market is called and the produced price serves as the opening price for the regular market. The existing literature documents that such markets *are* informative despite the lack of commitment (see e.g. Biais et al., 1999, Cao et al., 2000, and Barclay and Hendershott, 2008). The reasons proposed all include a reduction in adverse selection due to either getting access to a larger pool of liquidity at the opening of the regular trading day (Biais et al., 1999) or information-sharing (Hong and Pouget, 2021).

We too document that prices and quantities are increasingly informative of final prices and quantities despite the lack of commitment. However, our proposed explanation for why this happens has nothing to do with adverse selection, which is inexistent in the New Zealand electricity market, but with the ability of iterative mechanisms to coordinate allocations across several markets, in our case, across several trading periods. We document that virtually all

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[1] We will argue in Section 2 that forward markets in electricity do not provide a substitute for commitment during the predispatch.

bid revisions involve several trading periods and provide examples illustrating how market participants use the predispatch market to reorganize their generation dispatch across time.

Finally, a natural concern about the New Zealand predispatch market is that it may foster tacit collusion, or at least facilitate the exercise of market power. Tacit collusion arises when market participants coordinate on a less competitive equilibrium without explicit communication or enforcement mechanisms. Markets with multiple equilibria are prone to tacit collision. Bolle (1992) and Ausubel et al. (2014) show that markets, such as the New Zealand electricity market, where participants submit supply functions typically have multiple equilibria. In such markets, high levels of market transparency can help participants coordinate on the least competitive equilibrium (see von der Fehr (2013) for a general argument, and Brown and Eckert (2022) for evidence in the Alberta wholesale electricity market).

We make no claims as to the nature - collusive or not - of the equilibrium in the New Zealand wholesale electricity market. After all, like most other electricity markets, the New Zealand electricity market is characterized by a small number of participants, repeated interactions, inelastic demand, and limited informational asymmetry, all conditions that are favorable to the emergence of collusion, or at least tacit collusion.

However, our results do not provide any indication that the predispatch market facilitates participants' coordination on a high price equilibrium: prices barely rise over the course of the predispatch and bid revisions are largely driven by new information arrival. Moreover, the exact mechanism through which predispatch could incrementally support such coordination is unclear. In a recent paper, Kamada and Kandori (2020) study what they call “revision games” where players can update their actions repeatedly until the market is called. The predispatch market can be seen as a revision game. They show that even a small probability of not being able to upgrade their action (in our context, market participants missing the deadline for submitting their bids) can help support coordination on a less competitive equilibrium. However, in their setting, play evolves over time to an increasingly competitive outcome as players update their actions. This is not borne out in our data: if anything prices increase very slightly (by less than one percent) over the course of the predispatch.

In a separate paper (Bergheimer et al., 2022), we explore the impact of the reduced uncertainty produced by the predispatch market on participants' ability to *unilaterally* exert market power. We find that the reduced uncertainty about residual demand facilitates the exertion of market power by market participants and, in particular, by hydro-based generators who can easily reallocate their intraday production to take advantage of price differences.

2 The New Zealand predispatch market for electricity

The current organization of the electricity market in New Zealand is the result of the economy-wide pro-market reforms that swept the country in the 1980s and 1990s. Before that, electricity production, transmission, distribution, and retail were all under public ownership and vertically integrated. Transmission was separated early on through the creation of Transpower, which today acts as the system operator. Between 1996 and 1999, the generating assets of the monopoly generation company were progressively split to make way for five independently-operated firms: Contact, Genesis, Meridian, Mighty River Power (now Mercury), and Trust Power. Distribution and retailing were also separated at that time, with the five incumbent generation companies inheriting the retail business of the former electricity monopoly.

The foundations for the electricity wholesale market were laid out in 1996. The design relies on a single settlement (dispatch) market where energy and reserves are co-optimized on the basis of the bids received by electricity producers and industrial consumers. Dispatch maximizes the difference between cleared demand and supply, taking physical constraints into account.[2] Co-optimization means that dispatch may occasionally deviate from the cost-minimizing dispatch when doing so reduces the cost of reserves. Prices are nodal, i.e. location-specific, reflecting the geography of the country and the large transmission losses that go with it.

Participation in the wholesale market is compulsory for all electricity producers and industrial consumers, including vertically-integrated firms. Electricity producers are asked to submit energy and reserve bids (more precisely, bid schedules, although we will continue using the term "bids" for simplicity) as well as maximal capacity and ramp-up and ramp-down constraints for each half-hour (trading period). Bids are specific to units or stations. Industrial consumers are also requested to submit bids.[3]

The market is cleared for each trading period sequentially. This means that the only dynamic consideration that the market model takes into account is ramp-up and ramp-down constraints. It starts with a predispatch market, that opens 36 hours before dispatch, where indicative prices and quantities are generated using exactly the same inputs and optimization model as for the final dispatch. Specifically, every 2 hours, Transpower runs the model over a 72-period horizon (the so-called long schedule) and, every half hour, it runs it over an 8-period horizon (short schedule). This means that, for every trading period, 24 indicative predispatch markets are run (initially at the frequency of once every two hours, then once every half an hour) prior to final dispatch.

During the predispatch, market participants can update these bids at their will until "gate closure" which happens one hour before dispatch (two hours before dispatch until June 28, 2017). After gate closure, restrictions apply. Intermittent generators (wind) and industrial consumers are expected to update their estimates of their generation and load after gate closure. Other market participants - generators - can only update their bids in exceptional circumstances (e.g. an unplanned outage) and can only change the quantity offered, not the price, starting from the highest price band. Commitment is limited. Wind generators and industrial consumers are never bound by their bids. Other generators are only committed by their last bids.

Real-time dispatch uses the latest load forecast, current generation, and the last submitted bids during predispatch as inputs to the market model and generates dispatch instructions at the frequency of once every 5 minutes.

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[2] Retail demand does not participate actively in the wholesale market. Forecast load is instead used when producing dispatch instructions. Alvey et al. (1998) describe the model used for scheduling, pricing, and dispatch (SPD) in detail.

[3] A bid schedule can have up to 5 price bands for generation bids, and up to 10 price bands for demand-side bids.

The wholesale market is complemented by a voluntary hedge market, where market participants take positions either on the Australian Security Exchange (ASX) (mostly) or in the over-the-counter market. This hedge market operates on a very different time horizon. Around 97% of traded contracts are monthly or quarterly contracts that cover all trading periods, or all peak trading periods, in a given month or quarter. This means that this hedge market does not provide a substitute for the lack of commitment in the predispatch market.

Market transparency is promoted at all stages. After each predispatch, Transpower publishes price forecasts, scheduled load at all consumption nodes, and the aggregate supply curve at reference nodes. In addition, individual market participants are informed about their cleared bids. The entire history of bids and offers during predispatch and all inputs to the final dispatch and pricing are published within two or three days. A website, WITS (which stands for Wholesale Information Trading System), provides real-time information about the state of the market and operational constraints, including prices, load, generation, outages, transmission constraints and flows between the North and South islands. Separate websites provide anonymized data on hedging positions and information about hydro reserves.

3 Data

Our data span the period between 1 January 2014 and 30 September 2018. For each half hour (trading period) and each node,[4] we observe the bidding behavior of market participants during the predispatch market, indicative prices and quantities generated by each predispatch, and final prices and quantities.[5,6] We additionally observe all public market-relevant information such as installed capacity at all nodes, load forecasts, planned and unplanned outages for each node and trading period, hourly regional weather realizations, and daily levels of hydro reservoirs.

Table 1 provides an overview of our bidding data and outcomes at different stages of the market. By default, each generator and each industrial consumer must submit a bid at the time of the first predispatch round for all the nodes at which they are active. The top panel of Table 1 shows that generation is the active side of the market during predispatch: bidding on the demand side mostly sticks to the minimum level of activity, whereas the median producer submits three bidding versions for the same node and trading period over the course of the predispatch.

The second panel of the table shows that prices go up by a little less than 1% over the course of the predispatch and that their dispersion goes down. Changes in node-level and aggregate prices display a similar pattern.

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[4] With some slight abuse of language, we call a node, not only the physical injection or exit point on the grid but every unique "node x bidding unit" observation. When two participants are active at a physical node, they face the same price, but their behavior may still differ. Likewise, several generating units owned by the same participant may be connected to the grid at the same physical node while submitting different bids.

[5] Transpower solves two versions of its program, one in which bids from industrial consumers are taken into account as submitted (the so-called price-responsive schedule), and one where they are replaced by a vertical demand at their maximum demanded quantity (non-responsive schedule). For the purpose of our paper, we use the price-responsive schedules for the predispatch data.

[6] Predispatch data are missing for 2,083 trading periods (2.5%) so our final dataset covers 81,146 trading periods. There is no indication of systematic bias in this censoring.

Table 1: Bidding behavior and market outcomes during predispatch

	# nodes	5%	25%	Median	75%	95%
Generation bids per trading period	77	1	1	3	5	11
Demand bids per trading period	35	1	1	1	2	6
Prices (NZ$/MWh)						
First predispatch price	89	9.5	43.5	57.8	79.0	158.6
Last predispatch price	89	23.2	47.4	58.3	75.1	123.2
Change from first to last predispatch	89	-58.3	-13.5	0.1	14.1	44.2
Node-level change from first to last predispatch	89	-60.3	-14.2	0.0	14.2	45.8
Generation (MWh)						
First predispatch quantity	89	3,392	3,966	4,797	5,307	6,061
Last predispatch quantity	89	3,386	3,964	4,781	5,289	6,043
Change from first to last predispatch	89	-248	-94	-12	64	223
Node-level change from first to last predispatch	89	-26	-1	0	0	26
Industrial consumers (MWh)						
First predispatch quantity	13	880	915	942	988	1,053
Last predispatch quantity	13	869	907	934	972	1,026
Change from first to last predispatch	13	-35	-6	8	29	73
Node-level change from first to last predispatch	13	-5	0	0	0	13

Notes: The unit of observation for bids is a trading period x node. Generation bids exclude bids from wind units. Bids are uniquely defined by time stamps. The unit of observation for prices and quantities is a trading period, except for the data on node-level changes. Nodal prices are quantity-weighted to produce an average price for the trading period. There are 81,146 trading periods with complete coverage for predispatch prices and quantities between 1 January 2014 and 30 September 2018. Last predispatch prices and quantities use the last bids submitted and updated load and wind forecast at the beginning of the trading period.

The third panel documents generation. Aggregate scheduled generation barely changes over the course of the predispatch (median change of 12 MWh, less than 0.25% of aggregate generation) but adjustments of the order of 5% can happen. Over the course of a typical predispatch, half of the nodes experience no change in dispatch levels. Comparing the distribution of market-level and node-level changes suggests that the changes that take place during the predispatch are not only the results of market-level changes in generation but also reallocation of production across generation nodes.

The last panel shows that industrial consumers account for approximately 20% of electricity consumption. Their scheduled consumption does not change much over the course of the predispatch, and when it does, it mostly goes down, in line with the observation that submitted demand schedules by industrial consumers adjust quantities downward for very high prices, but are essentially vertical otherwise.

Table 2 provides summary statistics for realized generation for each technology. Schedulable hydro accounts for 55% of electricity generation on average. It is followed by geothermal and gas (combined cycle), with 18% and 10% generation share, respectively.

Technologies differ in their production profiles. Given its importance in the New Zealand electricity mix, hydro generation is active both off-peak and on-peak (with a smaller proportion of nodes active during off-peak time). Cogeneration and geothermal are two baseload technologies with little variation in generation levels and stable production patterns independent of the time of the day, as witnessed by the stable fraction of nodes active both during peak and off-peak

Table 2: Characteristics of realized generation

	#	% active nodes		Generation (MWh)				Gen. share
	nodes	off-peak	peak	Mean	SD	Min	Max	Mean
Coal	4	0.25	0.33	117.0	130.0	0.0	500.0	0.02
Cogeneration	8	0.92	0.94	200.0	42.0	40.0	374.0	0.04
Diesel	1	0.00	0.01	0.0	4.0	0.0	156.0	0.00
Gas, combined cycle	3	0.62	0.63	460.0	195.0	0.0	1,139.0	0.10
Gas, open cycle	5	0.14	0.38	87.0	98.0	0.0	391.0	0.02
Geothermal	12	0.94	0.94	798.0	64.0	0.0	888.0	0.18
Hydro, run of river	8	0.79	0.91	176.0	66.0	26.0	319.0	0.04
Hydro, schedulable	36	0.77	0.89	2,604.0	658.0	917.0	4,438.0	0.55
Wind	11	0.89	0.89	247.0	138.0	0.0	589.0	0.05

Notes: The unit of observation is a trading period (N = 81,146). A trading period is considered to be a peak trading period when generation in that trading period belongs to the top 10 percentile of generation observed in the sample. One generation node consisting of a battery excluded.

times and the low standard deviation relative to mean generation. Wind generation is highly variable, but its production profile is independent of the state of demand. Finally, thermal production varies considerably and, except for combined cycle, increases during peak times, reflecting the role of these technologies in the electricity generation mix.

4 The role for a market

Economists since Hayek have valued markets, and the prices they generate, for their ability to enable “rapid adaptation to changes in the circumstances of time and place” facing decentralized economic agents (Hayek, 1945, p. 524). In this section, we quantify the role that markets, i.e., short-run, close-to-market coordination mechanisms, play for the New Zealand electricity wholesale dispatch.

Table 3 provides a first indication of the residual exogenous uncertainty that prevails in the system 36 hours before dispatch. The system operator Transpower produces load forecasts for all nodes not participating in the wholesale market (essentially retail nodes). These are used as inputs to the predispatch and dispatch models. In addition, windmill operators have a *bona fide* obligation to submit accurate production forecasts and must update those at least once every 30 minutes within 2 hours of dispatch. The table shows that wind generation and load tend to be overestimated at the time of the first predispatch. As these effects go in opposite directions, their net effect is symmetric around zero, with most observations falling within 6% of the actual market size.

What impact does uncertainty about wind and load, combined with other short-run changes in production and transmission circumstances, have on the actual allocation of generation? To answer this question, we apply machine learning techniques to predict prices and generation at each production node based on information available before bidding starts. Any discrepancy between our best prediction and the observed allocation provides a measure of the residual uncertainty about final allocations that remains 36 hours before dispatch, and it serves as a

Table 3: Load and wind forecast errors

	5%	25%	Median	75%	95%
Demand forecast errors (MW)	-230	-86	-11	60	218
Demand forecast errors relative to market	-4.9	-1.9	-0.3	1.4	4.8
Wind forecast errors (MW)	-142	-61	-16	30	112
Wind forecast errors relative to market	-3.2	-1.3	-0.4	0.7	2.5
Net forecast errors (MW)	-248	-93	3	96	274
Net forecast errors relative to market	-5.4	-2.0	0.1	2.1	5.7

Notes: The unit of observation is a trading period ($N = 81,146$). Forecast errors for load are computed as the difference between forecast load in the last and first predispatch. Wind forecast errors are computed as the difference between the final forecast at dispatch time and the wind forecast for the first predispatch. Total generation in the first predispatch is used as reference to compute the relative numbers.

benchmark for the role of markets to coordinate supply and demand.

We consider two broad sets of models: LASSO penalized regressions and random forests. The models include as predictors very much the same kind of information that Transpower uses to predict load (weather, seasonal, week and hour-of-the-day variables, lagged dependent variable) as well as node-specific information and system-level information about generation, such as hydraulic information about reservoirs and outage status.[7] Importantly, the model relies only on information available 36 hours before dispatch. Generation and prices are predicted at the node level. We focus on average predictions for prices due to higher volatility in prices.[8] We split the sample into training and testing observations and provide summary statistics on the performance of predictions on the testing set.

Table 4 summarizes the results from these prediction models. The predictive power of the models is evaluated based on the mean absolute errors (MAE) between the prediction and the outcome of the final predispatch (in MW), root mean squared error (RMSE), and R^2.

The top panel describes the results for node-level generation, where nodes are grouped into technological categories for reporting purposes. The results indicate large differences across technologies in terms of predictability. Combined cycle gas and geothermal generation are highly predictable. Open cycle gas and wind generation less so. Our specification of random forests performs better than LASSO. As a benchmark, we compare the results of the first predispatch as a prediction of the last predispatch. Our predictions tend to outperform predictions produced by the first predispatch on all metrics.

The bottom panel summarizes results for quantity-weighted prices at the island level. Prices are less predictable than generation, but our model still outperforms the prices generated by the first predispatch. The predictions are substantially less noisy than the first predispatch

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[7] It is worthwhile to note that the exercise we carry out is different from the one that Transpower solves. Transpower seeks to predict load, which it uses, *together with the bids submitted by market participants*, as an input to the New Zealand electricity market model to pin down generation dispatch. What we are doing is exploring to what extent we can bypass the market (i.e., participants' bids) and predict final generation allocations based on information available 36 hours before dispatch.

[8] Nodal prices can be volatile, aggregation at the level of the island smooths this variability and improves accuracy.

Table 4: Residual uncertainty about generation allocation and prices

	MAE			RMSE			R2		
	F	L	P	F	L	P	F	L	P
Node-level generation									
Overall	6.48	11.12	9.30	10.12	15.51	17.40	0.84	0.67	0.60
- Hydro, run of river	2.77	4.07	3.47	4.21	5.51	6.81	0.86	0.75	0.68
- Hydro, schedulable	8.12	12.92	10.93	11.72	16.97	18.76	0.84	0.69	0.60
- Gas, combined cycle	15.43	34.55	24.44	27.94	53.37	57.02	0.94	0.80	0.77
- Gas, open cycle	8.24	12.78	10.72	14.02	18.47	23.46	0.73	0.55	0.41
- Geothermal	1.28	4.61	1.67	3.82	8.46	6.38	0.94	0.71	0.82
- Coal	16.18	32.55	26.04	28.12	47.61	56.12	0.90	0.69	0.61
- Wind	6.71	9.74	11.09	9.08	12.39	15.14	0.77	0.57	0.48
Average prices									
- North Island	9.12	12.21	20.61	15.72	19.07	32.94	0.73	0.60	0.35
- South Island	8.67	12.03	19.75	14.26	18.02	37.35	0.78	0.66	0.33

Notes: The unit of observation for generation is a node x TP. The unit of observation for prices is a TP. F=forest predictions, L=Lasso predictions, P=first predispatch. The results only include testing observations. MAE stands for mean absolute errors (in MW) between the prediction and last predispatch, RMSE stands for root mean squared error. The top 0.1% observations with high prices (either final price or predispatch) are censored due to the importance of outliers driving the R^2 measure.

outcomes, which have metrics twice as large as the forest models.

This suggests that there is substantial reallocation between the first and the last predispatch. While some of this reallocation can be predicted, not all of it can. There remains a good amount of uncertainty about final allocations 36 hours before dispatch. This provides a role for a market. Comparing the numbers in Table 3 and Table 4, this uncertainty is not limited to the aggregate level of generation needed (on top of wind) but also to the allocation of generation across units.

5 Price and quantity discovery during the predispatch

In this section, we document the process of price and quantity discovery during predispatch. We first show that predispatch prices and quantities are increasingly informative of final prices and quantities. These patterns are consistent with the hypothesis that the predispatch generates information. We then zoom in on bid revisions and find that (1) bid revisions are more frequent during the short schedule part of the predispatch, and that (2) everything else equal, bid revisions are more frequent when new information arises (wind and load forecast revisions, new outage announcement). Finally, we exploit the change in gate closure in June 2017 to alleviate the concern that price discovery may actually be happening in the contemporaneous spot market.

5.1 Convergence and increasing informativeness of predispatch prices and quantities

The first part of our empirical exploration into price and quantity discovery in the predispatch market builds on an approach first implemented by Biais et al. (1999) to study price discovery in the preopening period of the Paris stock exchange.

Let q_{nt}^{r} denote the indicative quantity for node n at time period t produced during the r^{th} round of the predispatch, with the convention that q_{nt}^{0} is the best forecast based on information available before the start of the predispatch.

For every predispatch round r, we regress the quantity revision over the entire predispatch on quantity revisions up to round r:

$$q_{nt}^{24} - q_{nt}^{0} = \alpha_r + \beta_r(q_{nt}^{r} - q_{nt}^{0}) + \varepsilon_{rnt}. \tag{1}$$

If predispatch quantities are uninformative, then β_r should be equal to zero. Conversely, if predispatch quantities are informative, and, in particular, if current predispatch quantities are the best predictor for final (last predispatch) quantities, then we expect $\beta_r = 1$.[9]

Regressions are carried out separately for each predispatch round to account for the non-stationary process of learning during the predispatch. We are thus comparing the same predispatch round, for different production nodes and periods. We run the equivalent regressions for prices. As best forecasts based on information before the predispatch, q_{nt}^{0} and p_{nt}^{0}, we use the forecasts produced by the random forest predictor from Section 4.

The top panel of Figure 1 reports the slope estimates for the quantity equation (1) and for the North Island price equation (the results for the South Island are qualitatively similar). Consistent with the hypothesis that the predispatch market generates information, the coefficient β_r increases over the course of the predispatch and reaches one by the end of the predispatch. The estimated slope coefficient for the price equation remains low until the beginning of the short schedule, suggesting that information aggregation is picking up only then. The slope for the quantity equation increases steadily over the course of the predispatch.

Section 4 showed that residual uncertainty at the time the predispatch market opens differed across production technologies. Production at combined cycle gas power plants and geothermal stations could be predicted with little uncertainty, whereas residual uncertainty remained high for production at thermal nodes. Figure 2 reports the result of running equation (1) separately for four different technologies: schedulable hydro, run-of-river hydro, combined cycle gas and open cycle gas. The result reflects the combination of the quality of the random forests forecast and the flexibility and/or exposure to last minute events of the specific technologies.

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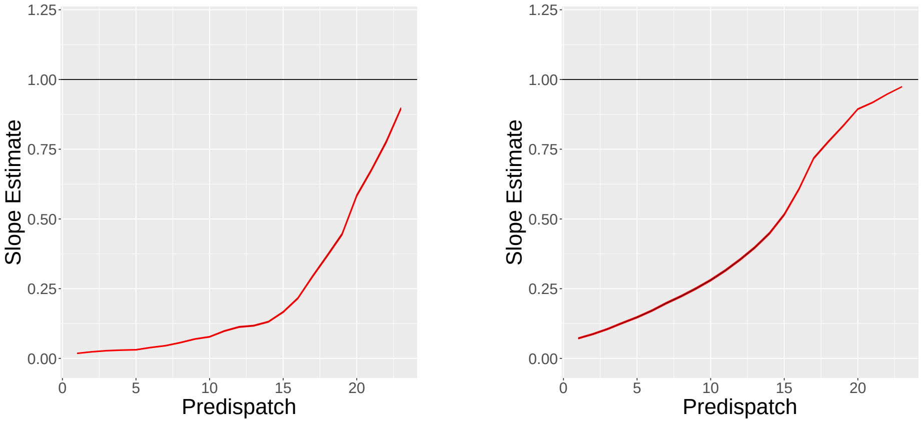
[9] Another way to see this is to rewrite (1) in the mathematically equivalent, but statistically less convenient, equation $q_{nt}^{24} = \alpha_r + \beta_r q_{nt}^{r} + (1 - \beta_r) q_{nt}^{0} + \varepsilon_{rnt}$. β_r can then be interpreted as the weight of round r's indicative quantity in predicting final quantity.

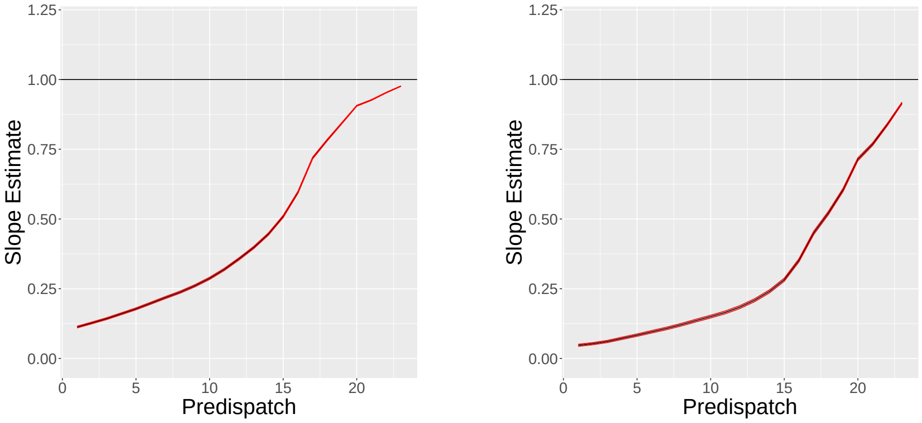
Figure 1: Evidence for price and quantity discovery



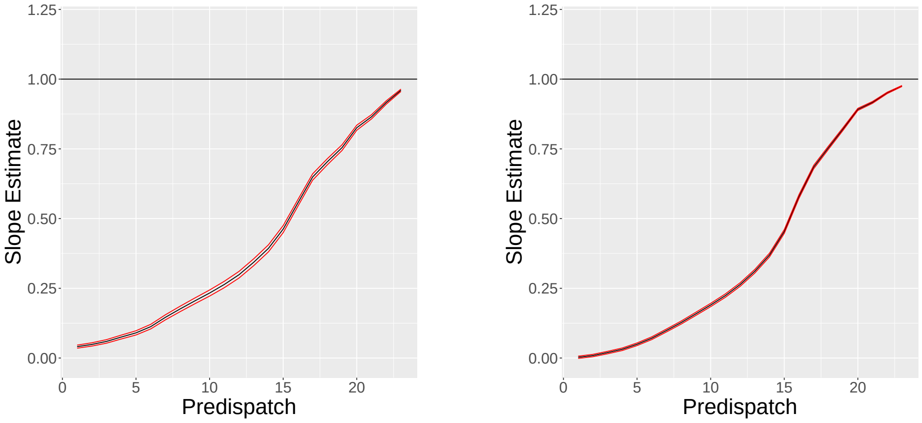
(a) Price convergence β (b) Quantity convergence β

Notes: The figure displays the estimated β_r coefficient and its 5% confidence interval for equation (1), and its equivalent for prices.

Figure 2: Quantity discovery differences across technologies



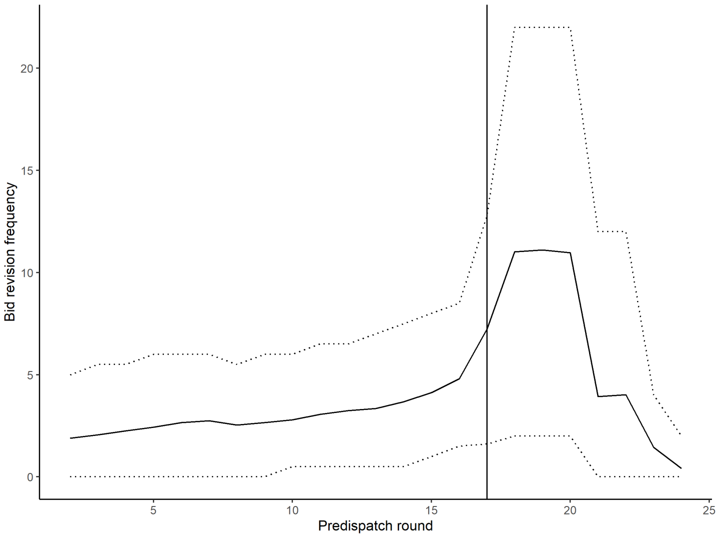
(a) Hydro, Schedulable (b) Hydro, Run of River



(c) Gas, Combined Cycle (d) Gas, Open Cycle

Notes: The figure displays the estimated β_r coefficient and its 5% confidence interval for equation (1) for a range of technologies.

Figure 3: Bid revision activity during the predispatch



Notes: The figure shows the frequency of node-level bid revisions, for a given predispatch round (mean in solid line; 10 and 90 percentiles in dotted lines). The unit of observation is a trading period x predispatch round x generation node. Wind generation nodes are excluded. Bid revision frequency is defined as the number of nodes subject to a bid revision per hour. Vertical line at round 17, the round at which predispatch switches from the long to the short schedule. Gate closure starts at round 20 until June 28, 2017 and at round 22 afterwards.

5.2 New information arrival and bid updates

We now zoom in on bid revisions as they drive price and quantity revisions during the predispatch market. Market participants can submit a bid revision any time during the predispatch, up to gate closure (conditions apply afterwards). A bid revision is characterized by a time stamp and the identity of the market participant who submitted it. We focus on generation-side bid revisions. Excluding wind, there are 447,719 bid revisions in our data. Virtually all of them involve several trading periods. Two thirds of bid revisions involve several nodes.

Figure 3 shows that bid revisions activity increases significantly after predispatch switches from the long schedule (when predispatch rounds last two hours) to the short schedule (when predispatch rounds last half an hour). At the beginning of the predispatch, about 3% of node-level bids are revised every hour. This increases to 11% when the predispatch switches to the short schedule. Bid revision activity then - as expected - drops at gate closure when constraints apply to bid revisions. Acceleration of trading activity close to the market end-time is also documented for preopening periods at stock exchanges (Biais et al., 1999).

We next explore the determinants of bid revisions. Let $y_{intr} \in \{0, 1\}$ denote whether firm i revises their bid for node n and trading period t during the r^{th} round of the predispatch.[10] Similarly, let $y_{itr} \in \{0, 1\}$ denote whether firm i revises any bid for trading period t in the r^{th} round of the predispatch.

We construct several measures of information arrival at the market and node level. First, we measure changes, during the predispatch, in available generation capacity. For each node, we

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[10] By convention, we say that a market participant revised their bids in the r^{th} round if they submitted a bid revision between the time of the $(r-1)^{th}$ and the r^{th} predispatch.

Table 5: Determinants of bid revisions

	Node-level				Firm-level		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ own capacity		0.00461	0.00464	0.00317	0.03994	0.04052	0.02971
		(0.00113)	(0.00115)	(0.00081)	(0.00804)	(0.00825)	(0.00545)
Δ others' capacity				0.00092			0.00128
				0.00005			0.00012
Lagged Δ net load				0.00004			0.00008
				(0.00001)			(0.00001)
Lagged Δ qty			0.00076	0.00064		0.00068	0.00058
			(0.00013)	(0.00010)		(0.00061)	(0.00047)
Lagged Δ price			0.00011	0.00004		0.00015	0.00005
			(0.00001)	(0.00001)		(0.00002)	(0.00001)
Round-node FE	X	X	X	X			
Round-firm FE					X	X	X
Obs. (million)	132.7	132.0	126.3	126.3	20.7	19.8	19.8
Adjusted R2	0.02	0.05	0.05	0.26	0.15	0.15	0.38

Notes: The unit of observation is a trading period x generation node x predispatch round for node-level regressions and a trading period x generation firm x predispatch round for firm-level regressions. At the firm level, a revision is defined as taking a value of one as long as the bid schedule of one of its plants is revised. Wind excluded.

define $\Delta\text{Capacity}_{nrt}$ as the absolute value of the change in available capacity between round $r-1$ and round r at that node (firm-level change in own capacity is defined as the mean of the node-level absolute value changes). This information is reported by participants alongside their bids. We use it as a proxy for unplanned outages.[11] Likewise, we define $\Delta\text{Capacity}_{(-i)rt}$ as the changes in available capacity at nodes owned by other market participants between round $r-1$ and round r, again measured as the sum of nodel-level absolute changes. Second, we measure market-level revisions in net load forecasts defined as the net change in load and wind forecasts between round $r-2$ and $r-1$. This information is available to participants when they bid in round r.

Finally, we construct two measures for the market feedback received in the previous round. Let $\Delta q_{ntr} = |q_{nt}^{r-1} - q_{nt}^{r-2}|$ describe the change in indicative quantity at node n and trading period t from predispatch round $r-2$ to predispatch round $r-1$ (Δp_{ntr} is defined analogously). A positive value for Δq_{ntr} can be the result of a previous change in bids (between round $r-2$ and $r-1$) or a change in market circumstances that leads the market model to select another point on the market participant's bid schedule at node n.[12] The interpretation for Δp_{ntr} is similar and the two variables will tend to be correlated, except that, because bid schedules are step functions, indicative quantities can change without indicative prices changing, and vice versa. Firm-level changes in indicative price and quantity are defined as the average of the node-level changes in price and quantity.

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[11] News about new and unplanned outages is available in real-time to all participants on the WITS system.

[12] Brown et al. (2018) find that participants in the Alberta's wholesale electricity market respond to rival offer changes, as revealed by the local market authority's historical trading reports.

We run two sets of linear probability regressions, one at the node level and, because two-thirds of bid revisions involve several nodes, one at the market participant level. Figure 3 shows that bid revisions are more frequent in later stages of the predispatch. Additionally, some technologies might be more prone to frequent revisions than others. Therefore, we control for round-node (in node-level regressions) and round-market participant fixed effects (in firm-level regressions).

Table 5 summarizes the results. All coefficients are positive, as expected, and significant at the 1% level, except lagged own quantity change in specifications 6 and 7. Changes in the available capacity of a market participant increases the likelihood that they revise their bids. Changes in the indicative price and quantity at a node during the previous round are also associated with an increased probability of submitting a bid revision for that node, but their explanatory power is small. Finally, market-level changes in generation and net load increase the probability of a bid revision and these variables have a strong explanatory power as evidenced by the increase in the adjusted R^2. These results confirm that the predispatch market reacts to new information.

5.3 Parallel markets and contribution to price and quantity discovery

A challenge when studying markets without commitment is the potentially confounding effect of contemporaneous transactions in related markets. In our case, this takes the form of spot market transactions, which are based on the last predispatch, happening at the same time as earlier predispatch rounds for future trading periods. How can we know that the informational role that we have documented is performed by the predispatch, rather than the contemporaneous spot market?

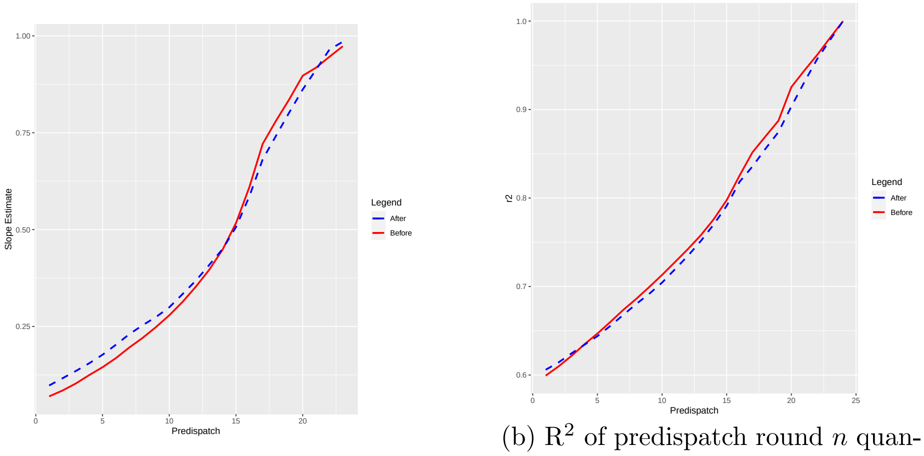
Subsection 5.2 offered a first answer to this question by showing that trading period-specific shocks explained part of the decision to submit a bid revision. However, some of these shocks may impact several periods, including the current trading period.

In this subsection, we exploit the change in the timing of gate closure that took place in 2017. Specifically, until June 28, 2017, gate closure lasted for two hours (predispatch rounds 21-24). Starting on June 29, 2017, gate closure was reduced to one hour (predispatch rounds 23 and 24). Under both regimes, market participants can continue to submit bid revisions in case of changes in wind forecasts, changes in industrial demand, or unexpected changes in available capacity (unplanned outage). There are two differences between the two regimes. First, to the extent that market participants are using the predispatch for other goals than reporting changes in generation capacity or load, they have an extra hour to do so after the policy change. Likewise, to the extent that information is generated by the spot market, the change in gate closure provides an extra hour.

Figure 4 shows convergence measures analogous to Figure 1 but splitting the sample before and after this market clearing change. In Panel (a), one can see that there is more convergence earlier in the predispatch sequence before the policy change. This is consistent with firms submitting their changes in rounds not affected by gate closure, which have restrictions on bidding changes.

One could be concerned that the estimation of convergence is affected by our predictions. In Panel (b), we perform an even simpler calculation. We compute the correlation between

Figure 4: Evidence from the change in gate closure



(a) Quantity convergence β

(b) R^2 of predispatch round n quantities to final predispatch

Notes: Panel (a) displays the estimated β_r coefficient for equation (1) before and after the regulatory change. Panel (b) displays the correlation (R2) between a given predispatch and the final predispatch. In both cases, one can see that there is higher correlation with final outcomes leading up to predispatch 21 during the *before* period.

quantities at a given predispatch round and quantities in the last predispatch. We find similar results. When gate closure is enforced by period 21, more revelation occurs before then. This “earlier” revelation of final outcomes cannot be explained by anticipated shocks outside of the predispatch market, which are unknown at the time. Therefore it suggests that active bidding in the market can have real effects on the final allocation in the market.

6 Why does price and quantity discovery happen without commitment?

So far, we have shown that market participants actively participate in the predispath market and that their revised bids contribute to making indicative predispatch prices and quantities increasingly informative. In this section, we explore the possible *private* incentives for bid revisions given the absence of commitment. After all, there is no reason for a market participant to submit a bid revision if they do not privately benefit from it.

We already noted that essentially all bid revisions involve several trading periods. Table 6 provides a detailed breakdown of the number of trading periods involved in a bid revision, by technology. The median number of trading periods in a bid revision is six, i.e. three hours, but it is much larger for cogeneration and geothermal units. Bid revisions for thermal plants typically involve eight trading periods. For hydro, bid revisions involve five periods on average.

Unlike most other electricity markets, including the Continental West European (CWE), the Iberian and Nordic markets in Europe, and PJM, California, and Colombia in the Americas, the New Zealand wholesale electricity market does not allow market participants to express intertemporal constraints on their production.[13]

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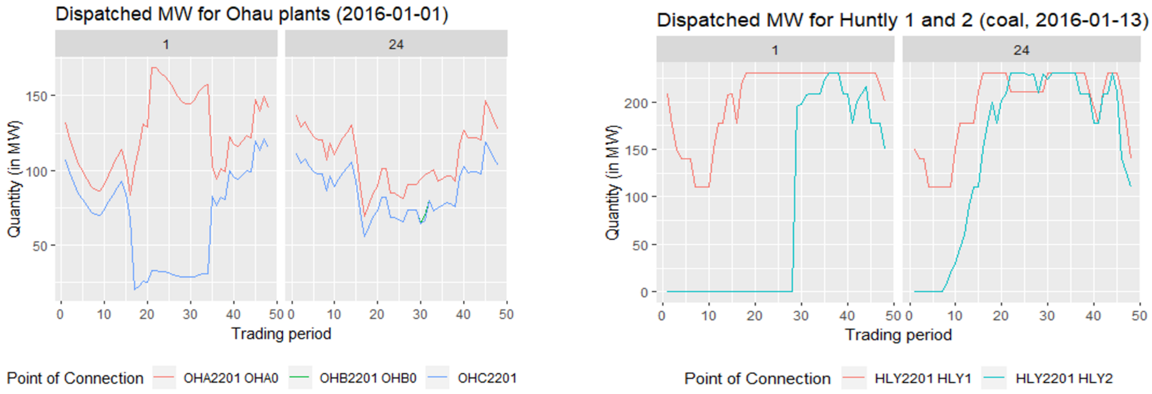
[13] These can take the form of a minimum revenue requirement as in the Iberian market (Reguant, 2014), explicit

Table 6: Number of trading periods involved in a bid revision (node level)

	# revs.	5%	25%	50%	75%	95%
Overall	5.72	1.0	3.0	6.0	15.0	48.0
- Coal	4.73	1.0	2.0	6.0	14.0	33.0
- Cogeneration	3.76	2.0	11.0	29.0	48.0	68.0
- Diesel	2.01	1.0	3.0	8.0	23.0	44.0
- Gas, combined cycle	4.62	1.0	3.0	9.0	21.0	44.0
- Gas, open cycle	2.73	1.0	3.0	8.0	20.0	48.0
- Geothermal	3.03	1.0	5.0	13.0	23.0	48.0
- Hydro, run of river	5.48	1.0	2.0	5.0	14.0	49.0
- Hydro, schedulable	6.25	1.0	3.0	5.0	12.0	48.0

Notes: The unit of observation is a node-level bid revision (timestamp x node). The first column indicates the average number of bid revisions per node and trading period. Note that we only include bid *revisions that happen during the predispatch*, i.e., revisions submitted after the first predispatch. $N = 980,131$.

Figure 5: Evidence for intertemporal optimization



(a) Connected hydro of Ohau

(b) Huntly coal power station

Notes: The figure shows scheduled generation over the course of the day (48 trading periods), as of the first predispatch (left panel) and the last predispatch (right panel) for the Ohau hydro plants (a) and the Huntly coal power station (b).

This means that the predispatch market, and the indicative prices and quantities it produces, is the only mechanism through which generation units are able to optimize their production profile over time. Such benefit of iterative mechanisms has been emphasized by Ausubel and Cramton (2004) among others.

Figure 5 provides two examples of intertemporal reallocation of production over the course of the predispatch. The left panel shows the evolution of scheduled production over the 48 trading periods (i.e. the entire day) of January 1, 2016 at Ohau A, B and C hydro power plants. Ohau A, B, and C are all operated by Meridian and are part of the Waitaki hydro scheme in the South Island. Ohau B and Ohau C are located at opposite ends of an underground canal, imposing, by design, an equal level of production (the two lines essentially overlap everywhere),

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fixed costs bids in addition to “simple” bids as in the Colombian market (Balat et al., 2022), block and linked orders and other multi-period contingent bids (Tirez et al., 2012) as used in the CWE area.

whereas Ohau A is on the other side of Lake Ohau. The figure shows that over the course of the predispatch, Meridian is able to align production across all three connected plants.

The right panel shows the evolution of scheduled production on January 13, 2016, for the first and second coal units at Huntly, a station located on the North Island and operated by Genesis. At the first round of the predispatch, the second unit was on only for 10 hours of the day, starting at trading period 28 (2 pm). By the end of the predispatch, its production plan aligns more closely to that of unit 1 and it is committed for a longer period, a useful property given the ramp-up costs of such units.

Improved intertemporal allocation of production is clearly a private benefit. To materialize it requires informative prices and quantities, so market participants have a collective interest in the quality of the predispatch. When a market participant revises their bids, they are not only optimizing their production but also improving information for other market participants. This provides a rationale for the observed active participation in the predispatch market and its informativeness, despite the lack of commitment.

7 Concluding comments

Wholesale electricity markets are notoriously incomplete (Wilson, 2002). Existing market designs are all pragmatic attempts to solve the complex allocation that electricity production and dispatch entail. The New Zealand electricity market is no exception. Its distinguishing feature is the use of a non-binding indicative predispatch market, before final allocations are decided.

Non-binding iterative markets are uncommon: preopening periods at stock exchanges and initial public offerings (IPOs) seem to be the other two examples. They raise the concern that participation is uninformative at best, manipulative at worst. We show that bid revisions in the New Zealand market are motivated by new information arrival and that predispatch prices and quantities are increasingly informative of final prices and quantities.

Our explanation for the informativeness of the predispatch market is that market participants derive a private benefit from effective price discovery, in the form of improved intertemporal coordination of production plans. This contrasts with the reasons given for the informativeness of preopening periods at stock exchanges and IPOs which rely on asymmetric information and adverse selection.

Could commitment nevertheless help? Introducing some form of commitment is on the agenda of New Zealand policy-makers. In October 2022, the Electricity Authority released a consultation paper on possible revisions to the wholesale market (Electricity Authority, 2022). One of the options considered is to introduce an hours-ahead market where, like in most other electricity markets, part of the supply and demand would be locked in.

Our results provide two insights on this question. First, our finding that predispatch prices and quantities are informative suggests that price and quantity manipulation, which the introduction of commitment would presumably seek to address, is not pervasive.[14] Second, the intertemporal

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[14] Biais et al. (2014) experimentally investigate the benefit of commitment in a setting inspired by preopening

nature of market participants' optimisation problem that we have documented suggests that careful attention should be paid to the way commitment is introduced unless some form of multiperiod bidding is introduced (Ausubel and Cramton, 2004).

Our paper has documented the efficiency benefits of information in terms of improved production scheduling. The flip side of information is that it also increases the market participants' ability to exert market power. We turn to this question in our follow-up paper (Bergheimer et al., 2022).

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periods. They find that binding offers improve the efficiency of trading over non-binding offers, exactly because they remove manipulative offers. Their setting is very different from the New Zealand predispatch, however, and does not include the sources of planning efficiencies that we have documented.

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