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The benefits of purely financial participants for wholesale and retail market performance: lessons for long-term resource adequacy mechanism design

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Abstract: In April 2015, Singapore introduced an anonymous futures market for wholesale electricity. Using data on prices and other observable characteristics of all competitive retail contracts signed from October 2014 to March 2016, a larger average quantity of open futures contracts that clear during the term of the retail contract a month before the retail contract starts delivery predicts a lower price for the retail contract. This outcome is consistent with increased futures market purchases by independent retailers causing lower retail prices. Consistent with the logic in Wolak (2000) that a larger volume of fixed-price forward contract obligations leads to offer prices closer to the supplier's marginal cost of production, a larger volume of futures contracts clearing against short-term wholesale prices predicts lower half-hourly wholesale prices. Both empirical results support introducing purely financial players to improve both retail and wholesale market performance. The paper then outlines how a regulator-mandated standardized futures market can be used as a long-term resource adequacy mechanism for the wholesale market regime.

Key words: financial participants, electricity markets, market design, market power, vertical integration.
JEL classification: G10, G13, L13

I. Introduction

Many restructured electricity supply industries have a small number of generation unit owners and many of these firms are vertically integrated into electricity retailing. This market structure limits both wholesale and retail competition which can increase both wholesale and retail electricity prices. Although these elevated prices may encourage

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entry by new suppliers, siting, building, and bringing on-line a new generation unit can take at least 18 months, and although this additional generation capacity may discipline the offer behaviour of existing firms, it may not be needed to serve demand throughout the year. Consequently, this mode of entry is a costly and high-risk approach to increasing both wholesale and retail competition.

In contrast, purchasing a fixed-price forward contract for wholesale electricity is a lower-cost and less risky approach to entering electricity retailing that can increase the extent of competition faced by incumbents in electricity retailing and wholesale supply. A new entrant purchases a fixed-price forward contract for wholesale energy for the term of the retail contract for the total amount of energy the customer is likely to consume. This forward contract hedges the vast majority of the short-term wholesale price risk faced by the entrant and also sets a lower bound on the fixed-price retail contract it can offer. Armed with a portfolio of fixed-price forward contracts at various delivery horizons in the future, the new entrant can compete against incumbent suppliers that own generation assets to sell retail contracts that deliver energy during these future periods.

If the new entrant is successful in obtaining retail customers and this forward contract is held to the clearing date, the generation unit owners that sold these forward contracts now have larger total fixed-price forward contract obligations when they submit their offers into the short-term market. By the logic in Wolak (2000), these generation unit owners have an incentive to submit offers into the short-term wholesale market that are closer to their marginal cost of production, which should result in lower wholesale prices.

This paper examines the empirical validity of the above logic that the introduction of a futures market for wholesale electricity increased competition in both electricity retailing and wholesale electricity supply in Singapore, which started a futures market in April 2015 for quarterly contracts for baseload electricity. These fixed-price forward contracts are traded on the Singapore Exchange Limited (SGX) and clear against the half-hourly Uniform Singapore Electricity Price (USEP) at a rate of 0.5 megawatt-hour (MWh) each half-hour of the quarter.

Using data on the prices and other observable characteristics of all fixed-price retail contracts signed between large consumers and electricity retailers from October 2014 to March 2016, I find lower prices for these retail contracts signed after the introduction of purely financial retailers enabled by the start of the standardized futures market. Moreover, after April 2015, I find that higher average volumes of open futures contracts that clear during the term of the retail contract during the month before the retail contract started delivering energy predict a lower retail contract price. Both of these empirical results are consistent with the presence of purely financial retailers increasing the competitiveness of retail market outcomes. I estimate that the total savings in energy purchased in retail contracts from 1 May 2015 through 31 March 2016 from the introduction of the futures market and average monthly volume of open positions in the market during that period is, depending on the econometric model specification, between 18 and 24 per cent of the total spending on retail energy contracts during this same time period.

Wholesale market performance in Singapore also appears to have improved as a result of the introduction of the futures market. I find that higher volumes of futures contracts clearing against the USEP during a half-hour predicts a lower wholesale

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price during that half-hour. This result is consistent with the forward market purchases of purely financial retailers increasing the aggregate fixed-price forward market obligations of generation unit owners in Singapore, which, by the logic described in Wolak (2000), should cause these generation unit owners to submit offer prices closer to their marginal cost of producing electricity, which then results in lower wholesale electricity prices. I estimate total wholesale energy cost savings from 1 July 2015 through 30 April 2016 from the introduction of the futures market and the open positions in the futures market during that period are, depending on the econometric specification, between 5 and 19 per cent of the total spending on wholesale energy over that same time period.

These retail and wholesale market price results support the argument that establishing a formal futures market can increase the competitiveness of both retail and wholesale market outcomes. Independent retailers can initially serve final consumers incurring minimal sunk costs of entry through purchases of wholesale energy from the futures market. As these retailers increase the number of customers served and system demand grows, they can invest in new generation capacity. This lower-cost and less risky entry strategy is particularly relevant for electricity supply industries where generation asset ownership is concentrated, a common initial condition in many restructured electricity supply industries.[1]

It is important to emphasize the need for liquidity in the futures market to the success of this strategy. Providing financial incentives for market participants to act as market-makers and post bid/ask spreads for minimum volumes of energy for each futures contract, as is the case in Singapore, is one approach to providing this liquidity. Without this requirement or a regulatory mandate for retailers or generation unit owners to participate in the futures market, it is unlikely that a sufficient volume of open positions will occur to produce the desired competitiveness benefits, particularly in markets with one or more suppliers that own a significant share of total generation capacity.[2]

Another argument in favour of establishing a market for standardized forward contracts and mandating participation by all retailers is that it provides a mechanism for ensuring long-term energy adequacy in the wholesale market regime. Generation unit owners and retailers in virtually all restructured markets complain about their inability to purchase or sell a significant quantity of energy in the future. If developers of new generation units are able to sell a significant fraction of the output from a potential new generation unit for several years into the future in standardized forward contracts for energy at attractive prices, this will enable them to obtain the necessary financing to build the new generation unit to serve demand in the future.

Establishing a market for standardized forward contracts and mandating that retailers purchase these contracts, at delivery horizons longer than the time needed to build a new generation unit, can reduce the barriers to new entry of generation units and ensure that there are adequate resources to meet a growing demand for energy at the lowest possible cost. Building on these empirical results, we present a detailed

[1] There has been an increase in the share of electricity supplied by non-incumbent producers in Singapore from 2.8 per cent in 2008 to 7.6 per cent in 2017 (EMA, 2018, p. 13).

[2] Suppliers that control a significant share of total generation capacity recognize the pro-competitive benefits of selling fixed-price forward contracts, particularly through an anonymous futures market.

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proposal for how a regulator-mandated market for standardized forward contracts can be used as a mechanism for achieving long-term resource adequacy.

The remainder of the paper proceeds as follows. Section II describes the economic logic underlying why a market for standardized forward contracts should improve the performance of both the retail and wholesale markets. Section III describes the structure of the Singapore electricity supply industry and the factors that led the Energy Market Authority (EMA), the Singapore electricity regulator, to encourage the formation of a market for standardized forward contracts for energy. Section IV describes the data used in our analysis and how each of the regressors used in the subsequent empirical analysis are constructed. Section V presents the empirical analysis of the impact of the introduction of the futures market on retail market performance. Section VI presents the empirical analysis of the impact of the introduction of the futures market on wholesale market performance. Section VII presents our proposed approach to ensuring long-term resource adequacy using a regulator-mandated market for standardized forward contracts and discusses the suitability of this proposal for wholesale electricity markets in other parts of the world. Section VIII concludes.

II. Forward commitments and market performance

There are two primary mechanisms through which forward commitments can influence wholesale market performance. The first mechanism was explored by Allaz and Vila (1993) in the context of a two-stage quantity-setting Cournot duopoly game, where each firm has the option to make forward sales in the first stage of the game before the short-term quantity-setting market operates in the second stage of the game. The authors find that the option to make forward market sales creates a prisoner's dilemma between the duopolists where each is better off entering into a forward contract given the other has not sold any energy in the forward market. In equilibrium, both firms sign forward contracts which commit them to more aggressive behaviour in the short-term market and lower price-cost margins than the no-forward-contract Cournot equilibrium.

The basic insight that a fixed-price forward contract commitment leads to more competitive behaviour in a short-term wholesale electricity market was investigated empirically by Wolak (2000), who found that the unilateral profit-maximizing price—what Wolak (2000) calls the 'best-reply price'—of a large supplier in the Australian wholesale electricity market was significantly lower and less volatile as a result of the fixed-price forward contract obligations held by this firm. McRae and Wolak (2014) demonstrate that for vertically integrated firms, a fixed-price retail load obligation is functionally equivalent to a fixed-price forward energy sale in terms of its impact on offer behaviour of this firm in the short-term energy market.

Bushnell *et al.* (2008) illustrate this point empirically by constructing Cournot models of three wholesale electricity markets in the United States (US) and computing the equilibrium with and without the fixed-price retail load obligations actually faced by the large vertically integrated suppliers in two of these markets. The authors demonstrate that in the two eastern US markets that have significant vertical integration between generation and retailing, substantially more market power would have been

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exercised in the short-term wholesale market if the large suppliers in these markets did not have substantial fixed-price regulated retail load obligations.

Chang and Park (2007) investigate the impact of fixed-price forward contracts in the early years of the Singapore market and find that fixed-price forward contracts led to lower wholesale market prices and less price volatility, consistent with the results in Wolak (2000).

The second mechanism through which forward markets impact overall market performance is discussed in Wolak (2014). He emphasizes that a liquid forward market for energy at delivery horizons longer than the time it takes to site and begin operating a new generation unit increases the competition that existing suppliers face to sell fixed-price forward contracts at these delivery horizons. That is because new suppliers can credibly compete with existing suppliers to provide energy at these delivery horizons. Clearly, an entrant cannot compete to supply energy in the forward market at shorter delivery horizons, because a new generation unit cannot be built in time to supply this energy. The incumbent suppliers recognize this and take it into account in setting prices at which they are willing to sell these shorter-term forward contracts.[3] Consequently, a liquid forward market for energy at delivery horizons longer than the time it takes to site and begin operating a new generation unit with likely produce the most competitive price for energy at this delivery horizon.

The primary mechanism through which the existence of a liquid forward market for energy affects retail market outcomes is by increasing the number of suppliers of retail electricity. A potential retail competitor no longer needs to construct a generation unit in order to supply retail electricity at a price that does not vary with the short-term market price. The potential entrant can purchase energy from the futures market for the term of the retail contract and obtain price certainty for the wholesale energy cost of serving this customer. The existence of a liquid forward market reduces the barriers to entry into electricity retailing and increases the number of competitors that the incumbent supplier faces for providing retail electricity.

By this logic, one summary measure of the amount of competition that incumbent suppliers face from purely financial retailers (that do not own generation capacity) is the volume of open positions in the futures market that clear during the term of the retail contract at the time the customer accepts bids from retailers to fill this contract. Our empirical analysis examines the extent to which both the existence of the futures market and the size of the open position in the futures market that clears during the term of the retail contract impact the ultimate price of the retail contract. We then explore the extent to which a larger quantity of futures contracts clearing during a given half-hour period leads to lower wholesale prices during that half-hour, consistent with the logic described above.

III. Singapore electricity supply industry

Singapore has a population of 5.7m people and a land area of 280 square miles, roughly the land area from San Francisco south to the city of San Jose on the San Francisco

[3] Wolak (2003) notes that, during the winter of 2001 in California, forward prices for energy delivered during the summers of 2001 and 2002 were massively higher than forward prices for energy delivered in the summers of 2003 and beyond for precisely this reason.

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Peninsula. It has GDP in US dollars *per capita* that is comparable to that in the US. Singapore has a high share of commercial and industrial electricity demand, which combined with its tropical climate, implies a relatively high load factor — the ratio of the annual average hourly demand to the annual peak demand. The annual instantaneous peak demand is approximately 7,000 megawatts (MW). Residential electricity consumption is approximately 15 per cent of total demand, relative to roughly 30 per cent in the US and Europe.

(i) Wholesale electricity market

The National Electricity Market of Singapore (NEMS) began on 1 January 2003. Singapore operates a single-settlement locational marginal pricing (LMP) market on a half-hourly basis.[4] Each half-hour of the day, the Energy Market Company (EMC), which operates the NEMS, sets LMPs for all generation locations and load withdrawal points in the Singapore bulk transmission network.[5] Figure 1 contains a map of Singapore. All generation units are located throughout the main island and several of the surrounding islands and are paid the LMP at their location for the energy they inject into the transmission network.[6]

Each half-hour, all loads pay the USEP, which is the quantity-weighted average of the LMPs across all load withdrawal points in Singapore.[7] Wholesale electricity prices in Singapore are typically close to the annual half-hourly mean value, but in slightly more than 10 per cent of the half-hours of the year they can rise to extremely high levels. To illustrate this point, Figure 2 plots the price duration curve for the USEP for the period 1 June 2015 to 31 May 2016. For each Singapore dollar (SGD) per megawatt-hour (MWh) price on the vertical axis, the corresponding value of the horizontal axis gives the fraction of half-hours in the period 1 June 2015 to 31 May 2016 that half-hourly values of the USEP are above that price level. Figure 3 plots the portion of the USEP Price Duration curve for the highest 10 per cent of half-hours of the year.[8]

Virtually all of the electricity consumed in Singapore is produced from natural gas-fired generation units, primarily using liquefied natural gas (LNG) delivered through the Singapore LNG terminal (SLNG). In 2015 and 2014, 95 per cent of the electricity was produced using natural gas and virtually all of this natural gas was burned in combined-cycle gas-turbine (CCGT) generation units. Figure 4 plots the licensed generation capacity by technology from 2010 to 2016. Most of the expansion in generation capacity during this time came from new entrants that found large loads to serve and built new generation capacity to serve these loads.

[4] All US wholesale electricity markets, PJM, ISO-NE, NYISO, MISO, ERCOT, and CAISO, operate locational marginal pricing markets. New Zealand also operates a single settlement LMP market.

[5] Lu and Gan (2005) describe the operational details of the energy and ancillary services markets for the NEMS.

[6] Chang (2007) presents an analysis of the competitiveness of the Singapore market during its first few years of operation.

[7] Similar mechanisms that charge electricity consumers geographic averages of LMPs exist in all US markets. In California, this is called load-aggregation point (LAP) pricing.

[8] A plot of the time series of half-hourly prices shows that most hours of most days, prices are near the mean, but unpredictably, and for short periods of time within the day, prices can be extremely high.

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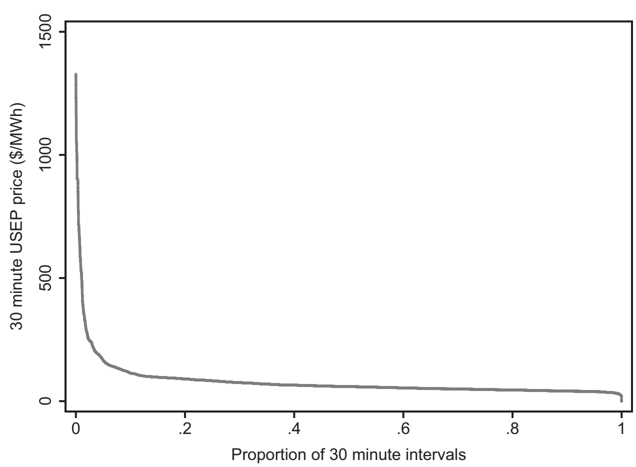
Figure 1: Map of Singapore

Figure 2: Uniform Singapore Electricity Price (USEP) duration curve for 1 June 2015 to 31 May 2016 (SGD/MWh)



Source: https://www.ema.gov.sg/statistic.aspx?sta_sid=20140826Y84sgBebjwKV

Figure 5 plots the capacity shares by supplier from 2010 to 2016. Although the capacity shares of the three largest firms has declined from 85 per cent in 2010 to 67 per cent in 2016, the industry is still extremely concentrated. In 2016, five firms control

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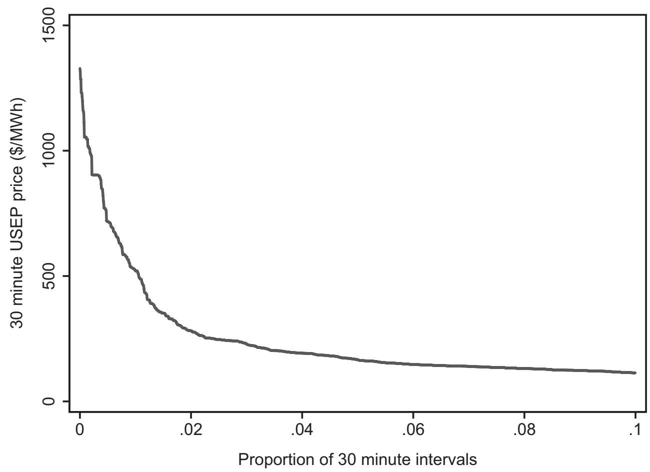
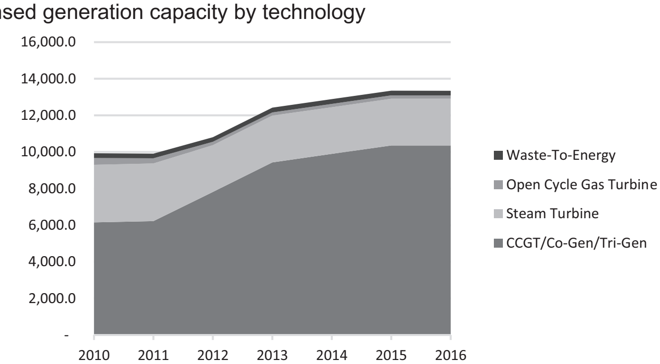
Figure 3: Upper 10 per cent of USEP duration curve for 1 June 2015 to 31 May 2016 (SGD/MWh)



Source: https://www.ema.gov.sg/statistic.aspx?sta_sid=20140826Y84sgBebjwKV

Figure 4: Licensed generation capacity by technology



Source: EMA (2018).

slightly more than 85 per cent of the installed capacity in Singapore. Figure 6 plots the annual electricity generation shares for 2010-16. The aggregate market share of electricity generation from the three largest firms is uniformly smaller than the capacity shares of these firms from 2010 to 2016. In 2016, the three largest firms had a generation share of 58 per cent versus a capacity share of 67 per cent. This outcome is consistent with the large suppliers (as measured by the amount of capacity they own) exercising unilateral market power and the small suppliers taking advantage of the higher offer prices submitted by the large suppliers by selling more electricity in the wholesale market.

Singapore has full retail competition for commercial and industrial customers with an average monthly electricity consumption of at least 2,000 kWh.[9] Customers meeting

[9] In a tropical climate like Singapore's, where air conditioners run continuously in most businesses, a retail shop or restaurant can have this average monthly consumption.

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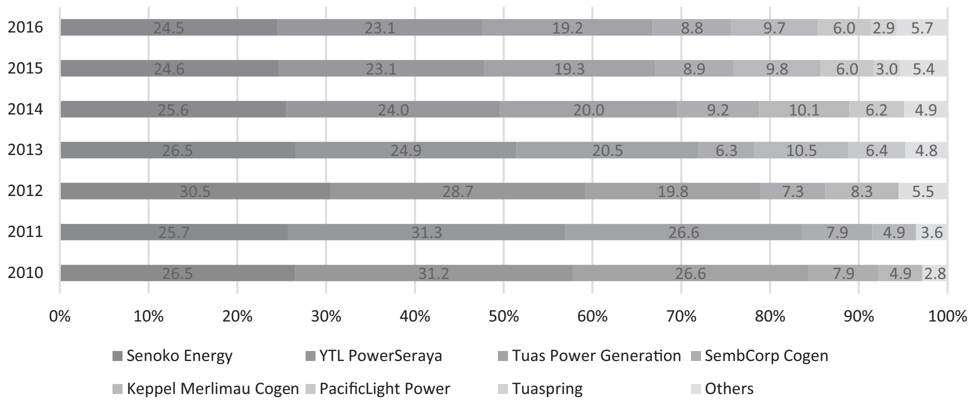
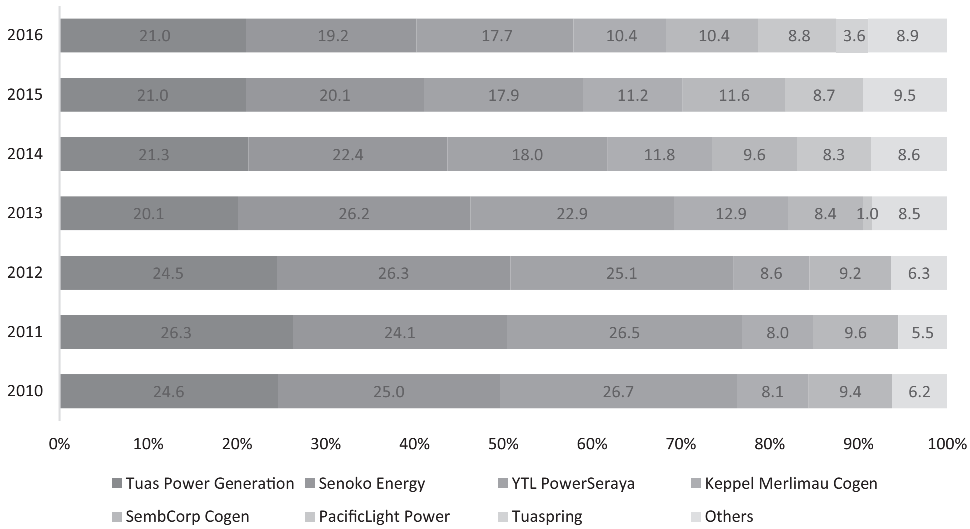
Figure 5: Licensed generation capacity shares by supplier



Source: EMA (2018).

Figure 6: Annual generation shares by supplier



Source: EMA (2018).

this criteria can choose their electricity retailer. Customers making this choice are called 'contestable'. All customers with average monthly consumption below 2,000 kWh are served by Singapore Power Services (SP Services) at a regulated tariff set by the EMA. Customers with monthly demand above 2,000 kWh that have not yet elected to choose a competitive retailer can either purchase their wholesale electricity demand at the half-hourly USEP or from SP Services at a regulated tariff set by EMA. A small fraction of these customers have chosen the first option, but the vast majority of potentially contestable customers are still served by SP Services at the regulated tariff. The EMA

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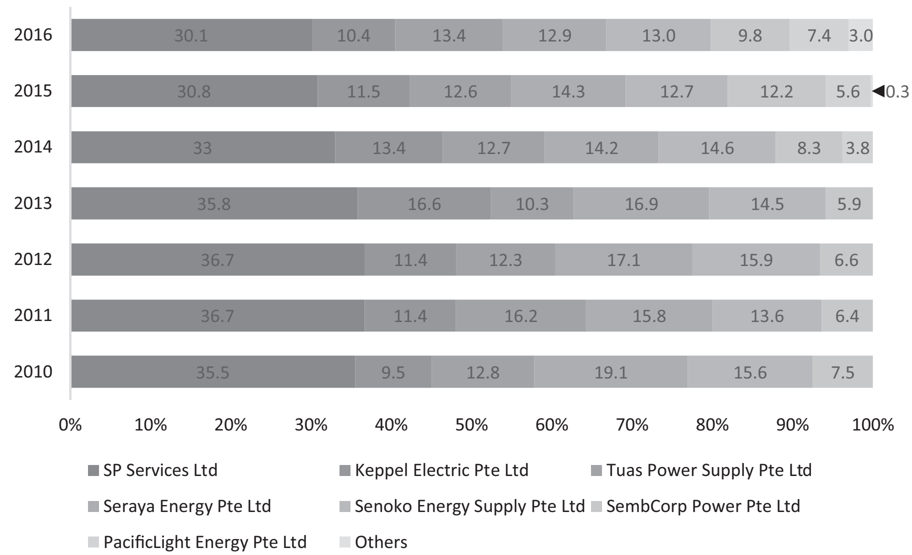
Figure 7: Annual energy sales shares by retailer



Source: EMA (2018).

of Singapore estimates that 95,000 business accounts, making up about 80 per cent of total electricity demand, meet the contestable customer requirement.[10] Figure 7 plots the annual energy sales shares of the major retailers in Singapore. SP Services still has the largest market share, but this has declined from 36 per cent in 2010 to 30 per cent in 2016, as more potentially contestable customers have decided to select one of the competitive retailers and become contestable.

All of the major retailers own significant amounts of generation capacity. The seven companies with the largest generation shares in 2016 in Figure 6 are also the seven retailers with the largest retail electricity sales shares in 2016 in Figure 7. The market shares of the electricity retailers in the competitive retailing segment reflect this entry strategy. The market shares of these retailers within this segment are close to their annual generation shares. For example, in 2016 Senoko Energy had a 19 per cent generation share and Senoko Energy Supply (its retailing arm) had a market share in the competitive retailing segment of 19 per cent. YTL PowerSeraya has a 18 per cent generation share in 2016 and Seraya Energy (its retailing arm) had a market share in the competitive retailing segment of 18 per cent. The approximate agreement between generation shares and competitive retailing shares also holds for the remaining five generation firms.

Historically, the entry path into electricity retailing was to construct a generation facility and sell energy to SP Services and contestable customers.[11] The generation facility provides the new retailer with a physical hedge against the short-term price volatility.

[10] https://www.ema.gov.sg/Electricity_Consumers.aspx

[11] For example, PacificLight Power Pte. Ltd built an 800 MW facility and entered as a retailer. Hyflux Ltd built a combined water desalination and power project and entered as a retailer.

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However, this entry strategy involves substantial sunk costs, and therefore involves significant financial risk, given the volatility of the USEP.

(ii) Singapore Exchange electricity futures markets

In an attempt to provide a lower sunk cost of entry path for electricity retailers and an additional stable source of revenues for new generation unit owners, the EMA established a futures market for wholesale electricity that clears against the half-hourly USEP. Starting in April 2015, these contracts traded in a bid-ask market on the Singapore Exchange Limited (SGX). In order to provide liquidity in the market for these contracts, the EMA implemented the forward sales contract (FSC) scheme which compensates market participants for posting bid-ask spreads for minimum volumes for each of the contracts available in the futures market.[12] During the first month of the futures market, there were no open positions taken in any of the futures contracts. Starting in June 2015, there were open positions in the September 2015 contracts. From that time until March 2016, there were open positions in virtually all outstanding contracts during all trading days.

These futures contracts would allow retailers that did not own generation units to enter the retail market by purchasing futures contracts to hedge the USEP volatility associated with offering a fixed-price retail contract to a contestable customer. A potential electricity retailer could partner with a financial market participant with a balance sheet to manage the financial risk associated with purchasing the futures contracts and sell contracts for retail energy for delivery during the period covered by the futures contracts purchased. Four retailers followed this entry strategy between the start of the SGX futures market until the end of our sample period in April 2016. By the end of 2017, there were more than ten retailers that had followed this entry strategy.[13]

The SGX futures contracts are quarterly baseload contracts. The EMA requires suppliers to post bid-ask spreads for contracts for nine consecutive quarters ending on the last day of March, June, September, and December. The contract size is 0.5 MWh for each half-hour of the day over the quarter. For a 90-day quarter the contract size is 1,080 MWh, for a 91-day quarter it is 1,092 MWh, and for 92-day quarter it is 1,104 MWh. Prices are quoted in SGD per MWh and the minimum tick size for bids and asks is 0.01 SGD/MWh. The final settlement price for the futures contract is the arithmetic average of the half-hourly USEPs over the expiring contract quarter, rounded to two decimal places. The last trading day for the contract is the last business day of the quarter.

Because of the tropical climate in Singapore, the relatively steady demand for air conditioning, and the large share of commercial and industrial demand, daily load shapes in Singapore tend to be relatively flat. Figure 8 plots the annual mean daily system load shape for 2014 and 2015. If Q_{hd} is the value of system load in MWh in half-hour h of

[12] Participants in the FSC scheme were awarded fixed-price forward contracts for energy at prices set by EMA for up to 3 years in the future in exchange for acting as market-makers in all outstanding futures contracts. The FSC is described in 'Forward Sale Contract (FSC) Scheme to Facilitate the Development of an Electricity Futures Market in Singapore', Request for Interest, 23 May 2013, EMA Document, https//www.ema.gov.sg/cmsmedia/Electricity/Electricity_Futures/23052013_RFI.pdf.

[13] See Table 3.1 of EMA (2018).

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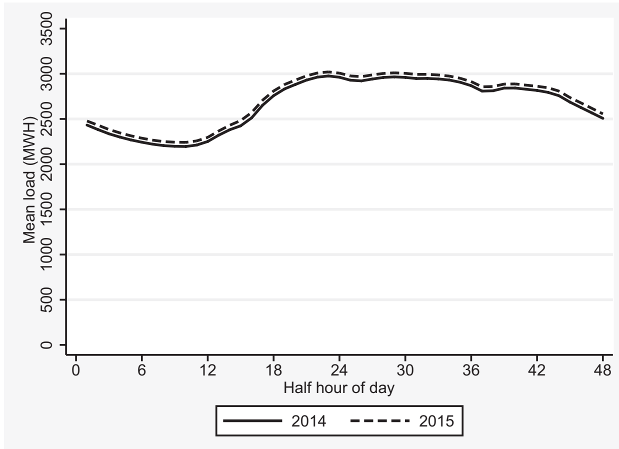
Figure 8: Annual average half-hourly daily load



Source: https://www.ema.gov.sg/statistic.aspx? sta_sid=20140826Y84sgBebjwKV

day d, each of the 48 points on the graph is equal to $\overline{Q_h} = \frac{1}{D}\sum_{d=1}^{D} Q_{hd}$ for $h = 1, 2, ..., 48$ where D is the number of days in the year. The fact that load shapes in Singapore are relatively flat limits the half-hourly quantity risk that the retailer faces by hedging a customer's half-hourly consumption with a forward contract that clears against the arithmetic average of USEPs during the term of the contract as opposed to that customer's half-hourly consumption.

An expression for the variable profit earned by a retailer using the futures market to hedge the USEP price risk can be derived using the following notation. Let Q_h equal the customer's consumption during half-hour h of the quarter, $QD_T = \sum_{h=1}^{H} Q_h$ is the customer's total consumption in the quarter, and H is the total number of half-hours in the quarter. Let P_R equal the fixed retail price (net of transmission and distribution charges) that the customer pays to the retailer, P_F the price paid by the retailer for wholesale electricity purchased from the futures market for 'delivery' during half-hour h, and $USEP_h$ the value of the USEP in half-hour h. Note that P_F is not indexed by h because each futures contract 'delivers' 0.5 MWh of electricity each half-hour of the quarter at a fixed price. Suppose that a retailer purchased QD_T in a quarterly futures contract to serve this customer. The variable profit during half-hour h earned by the retailer from serving this customer with this futures market purchase at P_F is equal to:

$$\begin{aligned}\pi(USEP_h, P_F) &= (P_R - USEP_h)Q_h + (USEP_h - P_F)\frac{QD_T}{H} \\ &= P_R Q_h - P_F\frac{QD_T}{H} + USEP_h(\frac{QD_T}{H} - Q_h). \end{aligned} \tag{1}$$

The first two terms in the second line of (1) are not impacted by wholesale market outcomes. $P_R Q_h$ is equal to the revenues the retailer earns from supplying this customer at P_R. $P_F\frac{QD_T}{H}$ is the cost of purchasing energy in the futures market for half-hour h. The residual quarterly wholesale energy cost risk faced by a retailer using an SGX

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futures contract to hedge the wholesale energy cost of serving this customer is equal to $\sum_{h=1}^{H} USEP_h(Q_h - \frac{1}{H}Q_T)$. This expected cost is higher the more the customer's actual consumption in half-hour h, Q_h, exceeds its average half-hourly consumption for the quarter, $\frac{Q_T}{H}$, during half-hours with the highest values of $USEP_h$.

Data on the total quantity of open positions and the closing price for each outstanding contract for each day from April 2015 to May 2016 was obtained from the SGX. The open position for a quarterly contract is the total quantity of contracted energy that a buyer has purchased in the futures market from a seller. The daily closing price for the contract is determined by SGX based on bid and ask prices and transactions prices for trades that took place during the day. This is the first data set that will be used in the empirical analysis of the impact of the size of open positions in the futures market and the prices contestable consumers pay for retail electricity.

(iii) Retail contract market

Competition for contestable retail customers takes place through a variety of mechanisms. The larger contestable customers run a formal procurement process where retailers submit price offers into a sealed-bid auction to provide retail electricity for a fixed term. Smaller contestable customers typically solicit offers from suppliers and negotiate their retail contract with a number of suppliers before settling on a single supplier.

Our analysis is based on information compiled by EMA on each retail contract signed by a contestable customer, which includes the supplier, the type of contract, the duration of the contract, monthly amount of energy procured under the contract, the start date of the contract and the price paid for energy under the contract. Virtually all of the retail contracts signed by contestable customers are fixed price. For retail contracts starting delivery between January 2013 and March 2016, a small fraction are indexed to the price of natural gas in Singapore and a larger, but still small, fraction are structured as a discount relative to the regulated SP Services tariff set by the EMA for that customer class.

These contracts range in duration from 3 months to 36 months, with a mean duration of approximately 12 months. Between January 2013 and the end of March 2016, over 15,300 retail contracts were signed. Data on the characteristics of each retail contract signed by a contestable customer is the second dataset used in the empirical analysis of the impact of open positions in the futures market and the price contestable customers pay for retail electricity.

IV. Open positions in futures contracts and retail prices

If a liquid futures market for wholesale electricity exists, a prospective independent entrant that would like to sell retail contracts delivering over the next 4 quarters (for example) can purchase SGX futures contracts that clear against the USEP during these 4 quarters. These futures market purchases provide the new entrant with wholesale price certainty for the quantity of energy purchased in the futures market each quarter. The retailer would likely purchase a significant fraction of these futures contracts before

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deciding to compete in the contestable customer retail market. Because the procurement process for a retail contract typically takes place before the month that the contract starts delivering energy, I use the average open position in futures contracts that clear during the term of the retail contract over all trading days in the month before the start date of the retail contract as a summary measure of the amount of competition faced by incumbent retailers for this retail contract.

Another factor determining the level of the retail price that a new entrant might offer is the average price paid for wholesale energy purchased in the SGX futures market to hedge this retail contract. If entering retailers are able to obtain lower prices from the futures market, then it is likely that they are willing to offer lower retail electricity prices during the period covered by these futures contracts. For this reason, we also compute an open-position-weighted-average of the daily closing prices of futures contract for all trading days in the month before the retail contract starts for all futures contracts 'delivering' during the term of the retail contract.

There are several other factors that could cause retailers to change their retail price offer. For example, retail contracts for a larger volume of monthly energy could sell at a discount. Longer-duration contracts could sell for more or less than shorter-duration retail contracts. Finally, a higher price of the major input used to produce electricity in Singapore—liquefied natural gas—should imply higher wholesale prices which would be reflected in higher retail prices.

Because the procurement process for each retail contract takes place before the winner of the contract starts making deliveries, I use information on average daily open positions, average daily closing prices, and average natural gas prices during the month before the retail contract starts as measures of market conditions at the time of the procurement process for the retail contract. For each month from June 2015, the first month of non-zero open positions in any futures contract, through April 2016, I compute the arithmetic average of the daily open position of each outstanding futures contract for all trading days in the month and daily-open-position-weighted average closing price for all trading days in the month.

These variables are computed in the following manner. Let QP_{fdm} equal the open position for futures contract f $(f = 1, 2, ..., 9)$ for trading day d $(d = 1, 2, ..., D(m))$ for month m and PC_{fdm} equal the closing price for futures contract f for trading d for month m, where $D(m)$ is the total number of trading days in month m. Compute

$$AQP_{fm} = \frac{1}{D(m)} \sum_{d=1}^{D(m)} QP_{fdm},$$

the average daily open position in futures contract f during month d, and

$$APP_{fm} = \frac{1}{D(m)} \frac{\sum_{d=1}^{D(m)} PC_{fdm} QP_{fdm}}{\sum_{d=1}^{D(m)} QP_{fdm}},$$

the daily open position weighted average closing price for month m. For each month. I repeat these two calculations for each outstanding futures contract during month m.

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For example, in April 2016 there are nine outstanding quarterly contracts: starting in April 2016 and ending the last day of June 2016, starting in July and ending the last day of September 2016, starting in October 2016 and ending the last day of December 2016, and starting in January 2017 and ending the last day of March 2017. The contracts that end in June 2017, September 2017, December 2017, March 2018, and June 2018 clear over the same time periods within the year as the 2016 contracts. This process yields a monthly average open position and a monthly weighted-average closing price for each outstanding futures contract for each month from June 2015 through April 2016.

To account for the fact that the futures market began operation in April 2015, an indicator variable is defined for all contracts starting delivery on and after 1 May 2015, the first month of retail contracts that could have been impacted by the existence of the futures market. *MARKET* is the indicator variable that equals zero for retail contracts starting delivery before 1 May 2015 and 1 for all contracts starting delivery on or after 1 May 2015.

For each retail contract, I construct the following two variables using the values of AQP_{fm} and APP_{fm} for each outstanding futures contract during month m. Suppose that the start date of a retail contract is 1 February 2016 and the contract is 1 year in duration. I construct the variable *AVGQ* for this retail contract as the weighted average of values of AQP_{fm} for January 2016 for contracts that cover the time period of the retail contract. For this example, there are five contracts that clear against half-hourly USEPs during the duration of the retail contract: (i) the quarterly contract that ends the last day of March 2016, (ii) the quarterly contract that ends the last day of June 2016, (iii) the quarterly contract that ends the last day of September 2016, (iv) the quarterly contract that ends the last day of December 2016, and (v) the quarterly contract that ends the last day of March 2017. *AVGQ* would assign a weight of 2/12 to AQP_{mf} for $m =$ January 2016 for the futures contract that ends in March 2016 because 2 months of this contract are contained in the period covered by the retail contract. The values of AQP_{mf} for $m =$ January 2016 for the next three futures contracts would receive weights of 1/4, and the final contract would receive a weight of 1/12 because only 1 month of the quarter is contained in the time period covered by the retail contract. The second variable, *AVGP*, is constructed in the same manner using the monthly averages of the daily-weighted average closing prices. These two variables are constructed for each retail contract. To account for the fact that there were no open positions for any futures contracts until June 2015, the values of *AVGQ* and *AVGP* were set equal to zero for all contracts starting delivery before July 2015.

To account for prices of the primary input to produce electricity in Singapore when the retail contract is under negotiation, I also construct the monthly average of the weekly SGX natural gas price index during the month before the retail contract began delivering. This variable is called *AVPLNG* and it is the average of the weekly price for all weeks with any days during the month of interest. Figure 9 plots the weekly LNG price and weekly average USEP to demonstrate the importance of controlling for changes in this input price over time in measuring the competitiveness benefits of introducing a futures market in Singapore.

There are other variables that control for the characteristics of the retail contract. The first is *IND*, an indicator variable for whether the contract was served by an independent retailer that does not own any generation units, and zero otherwise. *DUR* is

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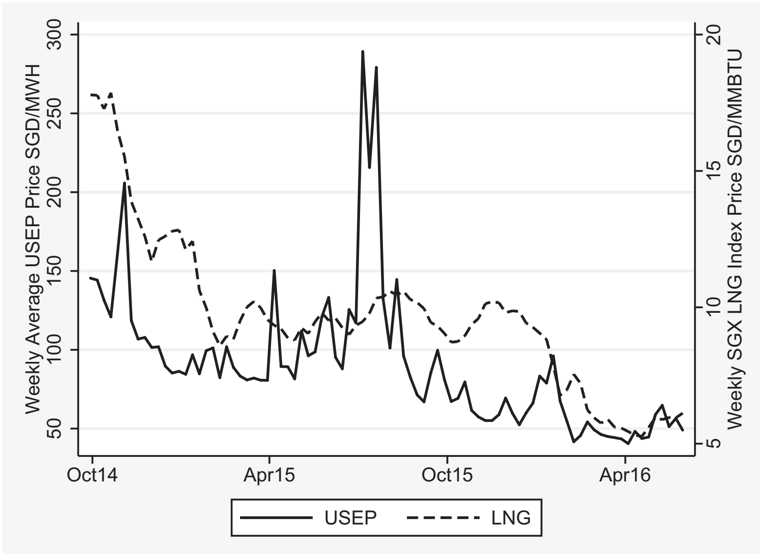
Figure 9: Average weekly USEPs (SGD/MWh) and weekly LNG prices SGD/MMBTU



Source for SLNG prices: Bloomberg

the duration of the retail contract in months. *CONS* is the monthly quantity of energy sold under the contract in gigawatt-hours (GWh). *TARIFF* is an indicator variable that takes on the value of 1 if the retail contract is a discount relative to the SP Services regulated tariff and zero otherwise. Because our LNG price index series does not start until 1 October 2014, all of our retail price regressions include retail contracts that started delivery on or after 1 November 2014.[14]

Because there was entry of new generation capacity in the Singapore market that could have impacted competition in both the retail market and wholesale market during the sample period, for each month from 1 January 2014 to the end of our sample, I compute the monthly reserve margin, $RSVMAR_m$, which is equal to $\frac{ICAP_m - PEAK_m}{PEAK_m}$, where $PEAK_m$ is the peak demand in megawatts in month m and $ICAP_m$ is the registered generation capacity in Singapore as of the start of month m. To capture the extent of competition generation unit owners face in month m, I use $RSVMAR_{m-1}$ in as the most up-to-date measure of supplier competition available when customers and retailers are negotiating retail contracts starting deliveries in month m. Figure 10 plots the reserve marginal for month m–1 and the weekly average USEP for month m. As the graph illustrates, higher values of $RSVMAR_{m-1}$ are likely to predict lower values of retail contract prices and USEPs during month m.

The hypothesis that the average volume of open positions in the futures market during the term of the retail contract as of the month before the retail contract started delivery increases retail competition yields several empirical predictions. The first is that after controlling for observable contract characteristics, a higher value of *AVGQ* for a

[14] Versions of both the retail price model in equation (2) and the wholesale price model in equation (9) for a longer pre-futures market phase without the LNG price index obtained qualitatively similar results in terms of the signs of the coefficients of interest for both models.

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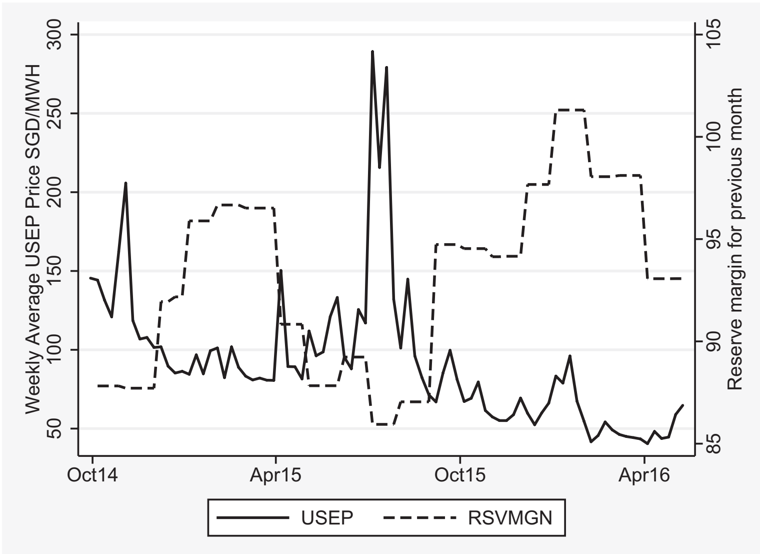
Figure 10: Average weekly USEPs (SGD/MWh) and monthly reserve margin from previous month (%)



Source for monthly installed capacity: https://www.emcsg.com/aboutu/publicrelations/marketreports

contract predicts a lower price for the retail contract. The second is that a higher value of *AVGP* predicts higher values for the price of the retail contract, because a higher average price of the futures contract used to hedge the retail contract offered by an independent retailer limits the retailer's ability to lower its retail price offer.

The baseline specification estimated takes the form:

$$P_c = \delta_j + \beta_0 + \beta_1 AVGP_c + \beta_2 AVGQ_c + \beta_3 AVGP_c * IND_c + \beta_4 AVGQ_c * IND_c + \beta_5 MARKET_c + X_c{'}\delta + \varepsilon_c \quad (2)$$

where the subscript c indexes contracts. P_c is the price of contract c, δ_j is a fixed effect for retailer j, X_c is a vector of additional covariates, and ε_c is a mean zero regression error. Table 1 reports estimates of various versions of equation (2) for the sample composed of fixed price contracts. Table 2 reports estimates of equation (2) for this same sample of contracts with all of the variables in logs. The standard errors are clustered at the retailer level for both sets of estimates.

Across all specifications that include *AVGP* and *AVGQ* we find evidence consistent with the two empirical predictions described above. Higher levels of *AVGQ* predict lower prices for the retail contract and higher levels of *AVGP* predict higher prices for the retail contract. The first result is consistent with the logic that a larger average volume of open positions in futures contracts that clear during the term of the retail contract in the month before the retail contract is signed implies greater competition from new entrants for this contract, which should and does predict a lower price for the contract. The second result is consistent with the logic that if independent retailers pay

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Table 1: Estimates for model of retail prices, levels: fixed price contracts

Variable	I	II	III	IV
AVGP	−0.009			0.034
	(0.012)			(0.015)
IND ∗ *AVGP*	−0.276			−0.377
	(0.033)			(0.045)
AVGQ	−0.123		−0.009	−0.017
	(0.013)		(0.010)	(0.010)
IND ∗ *AVGQ*	−0.055		0.013	−0.108
	(0.098)		(0.114)	(0.096)
DUR	−0.508	−0.316	−0.331	−0.332
	(0.196)	(0.175)	(0.168)	(0.161)
CONS	−1.993	−2.034	−2.033	−2.074
	(0.449)	(0.468)	(0.469)	(0.470)
AVGLNG	4.959	2.719	2.796	2.855
	(0.490)	(0.434)	(0.465)	(0.469)
RSVMAR	−0.730	−1.750	−1.693	−1.576
	(0.199)	(0.241)	(0.260)	(0.257)
MARKET		−16.823	−16.143	−17.784
		(2.085)	(2.609)	(2.686)
CONSTANT	158.555	279.465	273.463	262.318
	(21.241)	(27.304)	(29.823)	(29.024)
N	7,666	7,670	7,666	7,666

Notes: Each model contains retailer fixed effects. Standard errors clustered at the retailer level reported in parentheses.

Table 2: Estimates for model of retail prices, logs: fixed price contracts

Variable	I	II	III	IV
ln(*AVGP*)	0.02490			0.02566
	(0.00754)			(0.00650)
IND ∗ *ln*(*AVGP*)	−0.10775			−0.13042
	(0.04663)			(0.05806)
ln(*AVGQ*)	−0.05336		−0.01452	−0.03971
	(0.00915)		(0.00270)	(0.00737)
IND ∗ *ln*(*AVGQ*)	0.03847		0.03075	0.02939
	(0.00919)		(0.01540)	(0.00794)
ln(*DUR*)	−0.06242	−0.04883	−0.05402	−0.05826
	(0.01412)	(0.01429)	(0.01370)	(0.01339)
ln(*CONS*)	−0.03309	−0.03201	−0.03232	−0.03308
	(0.00248)	(0.00262)	(0.00262)	(0.00252)
ln(*AVGLNG*)	0.37734	0.21600	0.25920	0.27934
	(0.02857)	(0.02906)	(0.02255)	(0.02343)
ln(*RSVMAR*)	−0.58166	−1.46267	−1.21138	−0.93216
	(0.09555)	(0.16792)	(0.13685)	(0.07298)
MARKET		−0.14470	−0.08408	−0.08732
		(0.01228)	(0.01137)	(0.00798)
CONSTANT	7.14007	11.49170	10.26090	8.97068
	(0.45589)	(0.81406)	(0.65500)	(0.33763)
N	7,663	7,667	7,663	7,663

Notes: Each model contains retailer fixed effects. Standard errors clustered at the retailer level reported in parentheses.

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a higher price to hedge their wholesale energy costs to supply a retail contract, they pass on a portion of this higher price in the retail prices they offer.

The interactions of $ln(AVGQ)$ with IND in the logarithmic specification are consistent with the logic that a larger value of $AVGQ$ has a smaller in absolute value impact on the price of the retail contract offered by an independent relative to an incumbent retailer. The coefficient on this interaction is typically positive and smaller in absolute value than the coefficient on $AVGQ$. This result is consistent with the logic that a larger value of $AVGQ$ increases the extent of competition faced by incumbent retailers from independent retailers. A larger value of $AVGQ$ could be the result of more purchases in the futures market by one independent retailer or more purchases by additional retailers. The available data on open positions in the futures cannot distinguish between these two reasons for an increase in $AVGQ$. In the levels specification reported in Table 1, none of the coefficient estimates on the $AVQP * IND$ interaction is statistically different from zero.

Both tables also contain estimates that exclude $AVGP$, $AVGQ$, and interactions of the these variables with IND, but include an indicator variable, $MARKET$. In both the levels and logs specifications that exclude these variables (column II), the coefficient on $MARKET$ is negative, indicating that prices for retail contracts that begin delivering on and after 1 May 2015 were lower than observably similar retail contracts signed before that date. Both the levels and logs specifications (column IV in both tables) that include $MARKET$, $AVGP$, $AVGQ$, and the interactions of $AVGP$ and $AVGQ$ with IND find that the coefficients on $MARKET$ and $AVGQ$ are both negative indicating that both the existence of the futures market and higher values of $AVGQ$ predict lower retail contract prices. The coefficient on $AVGP$ also remains positive in both of these regressions.

The results in this section provide strong empirical evidence consistent with the hypothesis that the introduction of a futures market facilitated entry by independent retailers, which increased competition in electricity retailing and reduced retail prices for contestable customers. In addition, the negative coefficient on $AVGQ$ in the regression that includes $MARKET$ implies that beyond the existence of the future market, more competition to supply retail contracts, as measured by the value of $AVGQ$, predicts lower retail prices. These results also demonstrate that futures prices for energy clearing during the term of a retail contract are an important predictor of retail prices. This result is also consistent with independent retailers using these contracts as a way to compete in electricity retailing.

The regression estimates can be used to obtain an estimate of the retail energy cost savings that resulted from the introduction of these contracts. For the specifications in terms of level of the retail price, the predicted price reduction for each contract is computed using the general expression

$$\Delta P_c = \beta_2 AVGQ_c + \beta_4 AVGQ_c * IND_c + \beta_5 MARKET_c. \tag{3}$$

In the regressions that exclude $AVGQ$ and $AVGQ * IND$, ΔP_c excludes these variables. In the regressions that exclude $MARKET$ or $AVGQ$, ΔP_c excludes this variable. For each regression and each definition of ΔP_c, I compute the estimated total retail energy cost savings for all contracts starting delivery on or after 1 July 2015 as a percentage of total retail energy spending on these same retail contracts. This magnitude is computed as

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Table 3: Counterfactual estimates for retailer contract revenues: fixed price contracts

	I	II	III	IV
Levels				
Realized contract revenues (Millions of SGD)	903	903	903	903
Change in contract revenues (Millions of SGD)	41	145	142	159
Reduction total (%)	5	16	16	18
Logs				
Realized contract revenues (Millions of SGD)	903	903	903	903
Change in contract revenues (Millions of SGD)	161	141	123	210
Reduction total (%)	18	16	14	23

Notes: Each column uses the model estimated in Table 1 for levels and Table 2 for logs used to construct counterfactual contract revenues.

$$Total\ Percent\ Savings = 100 \times \frac{\sum\limits_{c \in C(f)} \Delta P_c \times CONS_c \times DUR_c}{\sum\limits_{c \in C(f)} P_c \times CONS_c \times DUR_c} \quad (4)$$

where $C(f)$ is the set of retail contracts starting delivery on or after 1 May 2015.

For the logarithms specification ΔP_c is computed as:

$$\Delta P_c = P_c[1 - exp(-\beta_2 ln(AVGQ_c) - \beta_4 log(AVGQ_c) * IND_c - \beta_5 MARKET_c)]. \quad (5)$$

Total Percent Savings is computed the same way as in equation (4) for this definition of ΔP_c. Table 3 presents the *Total Percent Savings* estimates for each of the model estimates in Tables 1 and 2. The estimated savings vary significantly across the various specifications. For the specifications that only include the *MARKET* indicator variable, the estimated savings are 16 per cent of actual total retail energy costs for contestable customers since 1 May 2015. For the specifications that include *MARKET*, *AVGQ*, *AVGP*, and their interactions with *IND*, the total savings are estimated to be between 18 per cent (the levels specification) and 23 per cent (the logs specification.) Any of these estimates imply sizeable retail cost savings to contestable customers due to the introduction of the standardized futures market in Singapore.[15]

Tables 4, 5, and 6 repeat the results in Tables 1, 2, and 3 for the sample that contains both fixed-price contracts and contracts that are indexed to the SP Services tariff. The results are qualitatively and quantitatively similar to the results with just the fixed price contract sample.

V. Open positions and wholesale market prices

This section examines the extent to which the introduction of the futures market for wholesale energy impacted the competitiveness of wholesale market outcomes. As discussed in section II, the level of fixed-price forward market obligations held by a generation unit owner determines the aggressiveness of the supplier's offers into the

[15] Although it is difficult to quantify the total cost of a mandated futures contract market the set-up costs and implicit payments made to the large suppliers for acting as market-makers these aggregate retail contract cost savings are significantly higher than the highest estimates of these costs.

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Table 4: Estimates for model of retail prices, levels: fixed price and tariff-indexed contracts

Variable	I	II	III	IV
AVGP	−0.011			0.038
	(0.016)			(0.013)
IND ∗ *AVGP*	0.090			0.001
	(0.023)			(0.020)
AVGQ	−0.127		−0.002	−0.013
	(0.011)		(0.013)	(0.015)
IND ∗ *AVGQ*	−0.082		−0.147	−0.131
	(0.057)		(0.054)	(0.056)
DUR	−0.521	−0.325	−0.333	−0.333
	(0.176)	(0.159)	(0.159)	(0.153)
CONS	−2.091	−2.147	−2.146	−2.188
	(0.492)	(0.512)	(0.513)	(0.514)
AVGLNG	4.788	2.515	2.538	2.644
	(0.508)	(0.505)	(0.581)	(0.594)
TARIFF	19.885	19.774	20.047	19.998
	(3.850)	(4.048)	(3.983)	(3.922)
RSVMAR	−0.727	−1.785	−1.763	−1.609
	(0.204)	(0.250)	(0.293)	(0.304)
MARKET		−17.511	−17.349	−18.968
		(2.315)	(3.141)	(2.976)
CONSTANT	160.147	285.562	283.565	267.922
	(21.683)	(28.001)	(33.089)	(34.052)
N	8,311	8,316	8,311	8,311

Notes: Each model contains retailer fixed effects. Standard errors clustered at the retailer level reported in parentheses.

short-term wholesale market. This logic implies that fixed-price forward contracts sold to independent retailers through the futures market should increase the quantity of fixed-price forward contract obligations of the generation unit owners, which should reduce short-term wholesale prices during the half-hours that these forward contracts clear. This section examines this hypothesis empirically using half-hourly USEPs, the system demand for that half-hour, weekly natural gas prices, and the total quantity of open positions in the futures market clearing against the short-term price during that half-hour.

To understand the mechanism that would cause a generation-owning retailer that sold futures contracts to an independent retailer to submit offer curves into the short-term market closer to their marginal cost curve, I derive below an expression for the variable profit of a vertically integrated retailer. Let P_R equal the fixed retail price charged by the vertically integrated retailer, Q_R equal the quantity of energy sold by the retailer at P_R, Q_C equal the quantity of fixed-price forward contracts sold by the retailer, and P_C equal the quantity-weighted average contract price. Define $DR(p)$ as the residual demand facing this supplier in the short-term wholesale market and p as the half-hourly wholesale price. As discussed in Wolak (2000), a supplier's residual demand curve is equal to wholesale market demand less the willingness to supply curve of all other suppliers besides this firm. The residual demand facing a supplier is the amount of the market demand at price level p that is left for that supplier to serve after accounting for the aggregate willingness-to-supply of its competitors. For simplicity, let c equal the constant marginal cost of generation for this retailer and τ equal the variable cost it pays for transmission and distribution services.

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Table 5: Estimates for model of retail prices, logs: fixed price and tariff-indexed contracts

Variable	I	II	III	IV
ln(*AVGP*)	0.02514			0.02614
	(0.00682)			(0.00568)
IND ∗ *ln*(*AVGP*)	0.00834			0.00016
	(0.00891)			(0.00954)
ln(*AVGQ*)	−0.05378		−0.01284	−0.03857
	(0.00839)		(0.00248)	(0.00665)
IND ∗ *ln*(*AVGQ*)	−0.00050		−0.02959	−0.00598
	(0.01432)		(0.01555)	(0.01388)
ln(*DUR*)	−0.06201	−0.04831	−0.05304	−0.05737
	(0.01358)	(0.01380)	(0.01339)	(0.01302)
ln(*CONS*)	−0.03271	−0.03154	−0.03184	−0.03262
	(0.00236)	(0.00248)	(0.00248)	(0.00244)
ln(*AVGLNG*)	0.35190	0.18395	0.22242	0.24573
	(0.03790)	(0.03618)	(0.03232)	(0.03750)
TARIFF	0.14704	0.14769	0.14816	0.14774
	(0.02422)	(0.02425)	(0.02439)	(0.02396)
ln(*RSVMAR*)	−0.58114	−1.47714	−1.25092	−0.96558
	(0.09557)	(0.16906)	(0.14061)	(0.09466)
MARKET		−0.14757	−0.09397	−0.09692
		(0.01336)	(0.00880)	(0.00614)
CONSTANT	7.18873	11.62856	10.52634	9.19210
	(0.46819)	(0.81432)	(0.66698)	(0.46091)
N	8,308	8,313	8,308	8,308

Notes: Each model contains retailer fixed effects. Standard errors clustered at the retailer level reported in parentheses.

Table 6: Counterfactual estimates for retailer contract revenues: fixed price and tariff-indexed contracts

	I	II	III	IV
Levels				
Realized contract revenues (Millions of SGD)	1027	1027	1027	1027
Change in contract revenues (Millions of SGD)	48	169	169	188
Reduction total (%)	5	16	16	18
Logs				
Realized contract revenues (Millions of SGD)	1027	1027	1027	1027
Change in contract revenues (Millions of SGD)	187	163	149	249
Reduction total (%)	18	16	15	24

Notes: Each column uses the model estimated in Table 4 for levels and Table 5 for logs used to construct counterfactual contract revenues.

In terms of this notation, the vertically integrated retailer's variable profit during a half-hour is equal to

$$\Pi(p) = (P_R - p)Q_R + DR(p)(p - c) - (p - P_C)Q_C - \tau Q_R. \tag{6}$$

The first term is the variable profit from retailing, the second term is the variable profit from sales in the short-term wholesale market, the third term is the difference payment for clearing fixed-price forward contracts, and the last term is the cost to the retailer of

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using the transmission and distribution grid. Following McRae and Wolak (2014), this expression can be re-written as

$$\Pi(p) = (P_R - c - \tau)Q_R + (P_C - c)Q_C + [DR(p) - (Q_R + Q_C)](p - c). \qquad (7)$$

All but the last term in this expression are unaffected by the supplier's offer behaviour in the short-term wholesale market. The last expression demonstrates that if a generation-owning retailer expects to sell more in the short-term market ($DR(p)$) than its fixed-price forward market obligations, ($Q_R + Q_c$), the supplier profits from raising short-term prices above its marginal cost of generation. Conversely, if the supplier expects to sell less than its forward market obligations in the short-term market, then it would prefer to set short-term prices below its marginal cost of production.

Suppose that initially the generation-owning retailer's variable profits are given by the expression in equation (7). Let Δ equal the additional fixed-price forward market obligations of this retailer that result from its sales in the futures market. Let P_F equal the price at which these futures contracts were sold. Equation (7) becomes

$$\begin{aligned}\Pi(p) = {} & (P_R - c - \tau)Q_R + (P_C - c)Q_C + (P_F - c)\Delta \\ & + [DR(p) - (Q_R + Q_C + \Delta)](p - c). \end{aligned} \qquad (8)$$

Because $\Delta > 0$, the generation-owning retailer now has an incentive to submit offers into the short-term market at or below its marginal cost of production for more of its output. This would imply short-term prices closer to its marginal cost of production for more half-hours of the year. If other generation-owning retailers have also sold futures contracts to independent retailers, these suppliers will also submit offers closer to their marginal cost of production and set lower wholesale prices during the half-hours that it has these incremental fixed-price forward market obligations. McRae and Wolak (2014) provide empirical evidence for both of these predictions about supplier behaviour for the New Zealand wholesale electricity market. They find higher levels of fixed-price forward market obligations led to offer prices for a supplier closer to its marginal cost of production and this offer behaviour results in lower market-clearing prices.

To investigate this hypothesis for the Singapore futures market, I run the following regression.

$$\begin{aligned} USEP_h = {} & Hour_j + Day_k + \beta_0 + \beta_1 Demand_h + \beta_2 (Demand_h)^2 + \beta_3 LNG\_Price_h \\ & + \beta_4 Open\_Pos_h + \beta_5 MARKETW_h + \beta_6 RSVMAR_h + \varepsilon_h \end{aligned} \qquad (9)$$

where $USEP_h$ is the USEP for half-hour h, $Hour_j$ is a fixed-effect for half-hour-of-the-day j, ($j = 1, 2, ..., 48$), Day_k is a fixed-effect for day-of-week k, ($k = 1, 2, ..., 7$), $Demand_h$ is the demand for half-hour h, LNG_Price_h is the weekly natural gas price for half-hour h, $Open\_Pos_h$ is the total open position for futures contracts that are clearing during half-hour h. For example, if h is half-hour 10 of 3 January 2016, then the quantity of open positions of quarterly contracts with a final settlement date of 31 March 2016 on 3 January 2016 would be the value of $Open\_Pos_h$. The hypothesis is that after controlling for the level of forecast demand for a half-hour and the price of the primary input fuel to produce electricity (LNG_Price), higher levels of $Open\_Pos$ (which correspond to higher values of Δ in our theoretical analysis) implies lower short-term

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Table 7: Estimates for model of wholesale prices

Variable	Levels I	Levels II	Levels III	Logs IV	Logs V	Logs VI
DEMAND	−0.293	−0.300	−0.305			
	(0.019)	(0.020)	(0.020)			
$\frac{(DEMAND)^2}{1000}$	0.028	0.029	0.029			
	(0.002)	(0.002)	(0.002)			
LNG_PRICE	4.539	5.058	5.305			
	(0.152)	(0.152)	(0.152)			
RSVMAR	−3.881	−4.396	−3.159			
	(0.180)	(0.166)	(0.153)			
OPEN_POS	−0.065		−0.194			
	(0.005)		(0.008)			
MARKETW		−1.674	25.425		−0.174	0.764
		(1.103)	(2.043)		(0.005)	(0.027)
ln(DEMAND)				−49.391	−49.646	−52.095
				(3.400)	(3.428)	(3.386)
$(ln(DEMAND))^2$				2.943	2.958	3.096
				(0.197)	(0.199)	(0.196)
$ln(LNG\_PRICE)$				0.626	0.647	0.624
				(0.008)	(0.008)	(0.008)
$ln(OPEN\_POS + 1)$				−0.041		−0.197
				(0.001)		(0.005)
$ln(RSVMAR)$				−2.688	−2.897	−1.987
				(0.064)	(0.062)	(0.064)
CONSTANT	1,161.612	1,223.819	1,125.837	222.278	224.321	231.087
	(66.925)	(66.830)	(65.106)	(14.789)	(14.905)	(14.714)
N	28,121	28,121	28,121	28,121	28,121	28,121

Notes: Each model contains half-hour of day fixed effects. Standard errors robust to heteroskedasticity reported in parentheses.

prices. $MARKETW_h$ is an indicator variable that equals 1 for all half-hours after the first half-hour of 1 July 2015 and is zero for all half-hours before that date. Similar to $MARKET_c$ for the retail contract analysis, this indicator variable accounts for the existence of positive open positions clearing against the half-hourly USEP.

Table 7 presents the results of estimating equation (9) with all of the variables in levels and in logs. Heteroskedasticity-consistent standard errors are reported below the coefficient estimates for all regressions. I also include versions which exclude $Open\_Pos_h$ and replace it with $MARKETW_h$. A third version of (9) includes both $MARKETW_h$ and $Open\_Pos_h$. For all these versions of the model in levels and logs, I find that the introduction of the futures market led to lower wholesale prices, and a higher level of $Open\_Pos_h$ predicts larger reductions in $USEP_h$.

The same procedure used to estimate the financial impact of the existence of and volume of open futures contracts on retail prices can be used to estimate their financial impact on wholesale prices. Specifically, for the levels regression, I compute the

$$\Delta USEP_h = \beta_4 Open\_Pos_h + \beta_5 MARKETW_h. \quad (10)$$

In the regressions that exclude $Open\_Pos_h$ or $MARKETW_h$, $\Delta USEP_h$ excludes these variables. I compute the estimated total wholesale energy cost savings as a percentage of total wholesale energy costs since 1 July 2015. This magnitude is computed as

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Table 8: Counterfactual estimates for wholesale market purchases

	Levels			Logs		
	I	II	III	IV	V	VI
Realized wholesale expenditure (millions of SGD)	3,548	3,548	3,548	3,548	3,548	3,548
Change in wholesale expenditure (millions of SGD)	429	73	175	756	676	683
Percentage reduction (%)	12	2	5	21	19	19

Notes: Each column uses the model estimated in Table 7 used to construct counterfactual wholesale market purchases.

$$TotalPercentSavings = 100 \times \frac{\sum_{h \in H(f)} \Delta USEP_h \times Demand_h}{\sum_{h \in H(f)} USEP_h \times Demand_h} \tag{11}$$

where $H(f)$ is the set of hours in the sample from half-hour 1 of 1 July 2015 forward and $Demand_h$ is demand during half-hour h.

For the logs specification, $\Delta USEP_h$ is computed as:

$$\Delta USEP_h = USEP_h[1 - exp(-\beta_4 ln(Open\_Pos_h) + \beta_5 Market_h)]. \tag{12}$$

Total Percent Savings is computed the same way as in equation (11) for this definition of $\Delta USEP_h$. Table 8 computes the *Total Percent Savings* for each of the three models estimated for the logs and levels specification. For the specifications that only include $MARKETW$ the estimated savings range from 2 per cent (the levels specification in column II) to 19 per cent (the logs specification in column V). For the specifications that include both $MARKETW$ and $Open\_Pos_h$ the estimated savings range from 5 per cent (the levels specification in column III) to 19 per cent (the logs specification in column VI). Regardless of how the financial impact of the introduction of a liquid futures market on wholesale prices is measured, the wholesale price impact is economically significant.

Before concluding this section, it is important to emphasize that because a substantial fraction of final demand in Singapore is covered by fixed-price forward market obligations, multiplying $\Delta USEP_h$ by $Actual\_Demand_h$ is likely to overestimate the wholesale market cost savings significantly. If $\alpha \in (0, 1)$ is the fraction of final demand covered by fixed-price forward market obligations, then $\alpha \times (Total\ Percent\ Savings)$ is a more appropriate figure for the wholesale energy cost savings from the introduction of the futures market.

VI. Broader implications of results

The results of the previous two sections provide strong empirical support for the argument that a liquid market for standardized forward contracts can significantly improve both retail and wholesale market performance. It is also important to emphasize that a major driver of the estimated economic benefits realized from the futures market in Singapore is the Forward Sales Contract Scheme that encourages market participants

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to act as market-makers and provide bid/ask spreads for minimum volumes for each of the outstanding futures contracts. The FSC Scheme ensures sufficient liquidity at reasonable prices for prospective retailers that would like to enter to sell retail contracts by purchasing futures contracts that clear during the term of the retail contract. This logic implies that in order for a futures market to provide retail and wholesale market competitiveness benefits, there must be a financial incentive or a regulatory mandate for suppliers or retailers to participate in this market to ensure sufficient liquidity.

Our empirical results raise the following two questions which I address below. Is there anything unique about the Singapore market that would imply that these results are not applicable to wholesale electricity markets in other parts of the world? Can a regulator-mandated market for standardized forward contracts serve as a basis for a long-term resource adequacy process?

(i) Is the Singapore experience unique?

Although there are some aspects of the Singapore market that imply introducing a regulator-mandated futures market would yield significant competitiveness benefits, there are a number of reasons to expect that these results would carry over to other wholesale electricity markets, particularly those in the US. There are also reasons to expect that the market performance benefits would be even greater for certain market designs relative to what was found for Singapore.

The high degree of concentration of generation ownership in the Singapore market—three firms own 58 per cent and five firms own 79 per cent in 2016—implies that without significant fixed-price forward contract coverage of final demand, these suppliers would have an incentive to exercise substantial amounts of unilateral market power in the short-term market.[16] The relatively flat load shape of most customers implies that purely financial retailers do not face a significant profit risk from hedging their wholesale energy costs using a futures contract that clears the same quantity of energy in each half-hour of the day during the quarter.

There are many electricity markets around the world with similar levels of concentration of generation ownership to that of Singapore. In addition, the profit risk facing a purely financial retailer in markets with a smaller load factor could be addressed by making the standardized forward contracts sold clear against a half-hourly system-load-weighted average rather than simply the arithmetic average of half-hours. Specifically, the half-hourly amounts of energy delivered under the futures contract, QC_h, would be computed as follows. Let QD_{hd} equal the system demand in half-hour h of day d. Define the share of quarterly demand in half-hour h of day d during the quarter as:

$$w_{hd} = \frac{QD_{hd}}{\sum_{d=1}^{D} \sum_{h=1}^{48} QD_{hd}}.$$

Suppose that the standardized forward contracts are for an entire quarter, so that D is the number of days in that quarter. Suppose that a supplier sells $Q(Contract)$ MWh of energy for the quarter. The half-hourly value of the energy delivered under the contract

[16] See Table 2.5 in EMA (2018).

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for both the buyer and seller of the contract is $QC_{hd} = w_{hd} \times Q(Contract)$. Specifically, the quarterly total amount of energy sold is allocated to half-hours in the quarter according to the actual load shape during that quarter. The values of the w_{hd} would be higher during the half-hours of the day when the value of system load is higher, which would make QC_{hd} higher during those half-hours. Alternatively, the market operator could specify values of the w_{hd} in advance based on historical values. The basic idea of this approach is to adjust the half-hourly values of the amount of energy sold in a quarter to match the hourly load shape to limit the deviations between QC_{hd} and what the average customer is consuming on an half-hourly basis.

The fact that all markets in the US use the LMP market design and typically have an analogue to the USEP at which loads purchase wholesale energy implies that it would be relatively straightforward to implement a standardized-forward contracts market for energy in each market in the US. Moreover, because all US markets have a day-ahead market and real-time market that allows purely financial entities to earn revenues from trading energy and patterns of transmission congestion between these two markets, these additional opportunities to earn revenues are likely to reduce the barriers to purely financial retailers entering these markets relative to the case of Singapore.[17] This should produce more vigorous retail competition, which should deliver greater economic benefits to consumers.

(ii) Mandated futures market for long-term resource adequacy

Virtually all jurisdictions with formal wholesale electricity markets have regulatory mandates aimed at maintaining an adequate long-term supply of energy at a reasonable price. Mandating participation in a standardized futures market for energy that clears against a spatially averaged half-hourly or hourly price such as the USEP in Singapore at long enough horizons to delivery to allow new entrants to compete to supply these contracts can be used as an alternative mechanism for ensuring long-term resource adequacy.

There is increasing dissatisfaction in the United States with the capacity-based long-term resource adequacy processes. This is particularly the case for regions with significant renewable energy goals. The firm capacity of a generation unit is typically defined as the amount of energy that the generation unit can produce under extreme system conditions, which makes defining the firm capacity of intermittent renewable generation units difficult, if not impossible. In addition, capacity-based resource adequacy processes procure firm capacity up to a pre-specified multiple of the peak demand, typically around 1.15, which limits wholesale price volatility and the incentive for investments in storage and active participation of final consumers in the wholesale market.

An energy-based long-term resource adequacy process has the potential to reduce the total amount of generation capacity required to serve the annual demand for energy, which can allow consumers to pay lower average wholesale prices, despite an increase in wholesale price volatility. Consumers can be protected from a significant fraction of this wholesale price volatility through the purchases of long-term contracts

[17] Jha and Wolak (2013) describe the opportunities for purely financial participants in the multi-settlement LMP markets that exist throughout the US.

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for energy. A liquid market for standardized forward contracts provides a mechanism for providing the necessary hedges against wholesale price volatility, as well as a mechanism for ensuring long-term resource adequacy if these mandated contract purchases are made far enough in advance of delivery to allow new entry to occur.

The wholesale market regulator could mandate that all load-serving entities in the region purchase and hold until delivery fixed-price forward contracts purchased from this standardized market equal to a pre-specified fraction of their final demand. For example, the mandate could be that all retailers purchase 97 per cent of final demand 1 year in advance, 95 per cent 2 years in advance, and 92 per cent 3 years in advance. Retailers that fail to meet this obligation would be subject to a significant per MWh penalty for every MWh their actual retail demand exceeds this forward market obligation.

These purchase mandates should be a sufficiently large fraction of the retailer's demand and continue far enough into the future to give the regulator sufficient confidence that energy adequacy will ultimately be achieved in the delivery year. To the extent the regulator is concerned that adequate generation capacity and other resources will be available to meet demand in the future, the regulator can increase the number of years in the future that the mandate to purchase exists from 3 years to, say, 5 years, and increase the percentage of demand that must be purchased in futures contracts in each year in the future, for example 98 per cent 1 year in advance, 97 per cent 2 years in advance, and 95 per cent 3 years in advance.

The requirement that all retailers purchase these standardized forward contracts is straightforward for the regulator to monitor. The requirement that these contracts are purchased and held to delivery by retailers ensures there are sufficient revenue streams for wholesale energy far enough into the future for the regulator to be confident that demand will be met in the future. This revenue stream provides consumers with wholesale price certainty for virtually all of their final demand far in advance of delivery to obtain a competitive price and provides a revenue stream to generation unit owners far enough in advance of delivery to allow them to bring on line sufficient resources to meet demand. Finally, the regulatory mandate that all retailers purchase these contracts, ensures liquidity in the futures market at the mandated horizons to delivery.

The mandate to purchase and hold these contracts to 'delivery' does not rule out market participants entering into other bilateral hedging arrangements. For example, a renewable resource owner might enter into a cap contract with a thermal resource owner where the thermal resource owner provides price spike insurance for a fixed quantity of energy each hour in exchange for an up-front payment. For example, a 50 MW solar resource might purchase insurance against prices above $100/MWh during the night-time hours for the capacity of this resource, to hedge the risk of a price spike when its unit is unable to operate. In this case the solar resource would pay an up-front fee to the seller of the contract in exchange for the payment stream $max(0, P(spot) - \$100/MWh) * 50MW$ from the seller of the contract during each night-time hour during the contract period.[18]

Using a standardized futures market for energy as the basis for a long-term resource adequacy process has the following advantages. First, it is technology and capacity neutral. There is no need for the regulator to determine the firm capacity of a generation

[18] The function $max(a, b)$ produces the maximum of the two arguments *a* and *b*.

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unit or set an overall capacity requirement. It leaves decisions about what is the least-cost mix of generation capacity, demand response, and storage needed to meet the demand for energy in the future to market participants, which are likely to be the entities best able to make these decisions. Second, it allows wholesale prices to reflect scarcity conditions that can make storage investments and active demand-side participation economic. This will increase the capacity factor of existing generation units, which allows the same annual demand to be met with less generation capacity, potentially reducing annual average wholesale prices.

The prices of these futures contracts can also be used to set the wholesale price component of the regulated retail price. For example, if the regulator would like to set the wholesale component of the regulated retail price for the coming year, it can use the weighted average futures price for contracts delivering in the following 4 quarters. Because the retailer has purchased these futures contracts to meet its requlatory mandate, the regulator knows that the retailer can at least supply energy at a retail price that includes this wholesale price. In this way, the regulator is able to set the regulated retail price for a vertically integrated electricity retailer. It simply uses the average futures prices for the relevant delivery horizon as the wholesale energy price component of the retail price.

It is important to emphasize that mandating purchases of these contracts by retailers is unlikely to create a stranded asset problem for retailers that lose load to other retailers. That retailer still owns a potentially valuable asset, which is the ability to purchase energy during the delivery period of the contract at the initial price paid for the futures contract. This retailer can sell this contract at the prevailing price for deliveries in the future and will be as likely to make money as lose money on this transaction if the futures contract was initially purchased at an efficient price in a liquid forward market such as the one proposed by this mechanism. Only in the extremely unlikely instance that system-wide demand falls substantially is there likely to be a stranded contract problem under this mechanism. However, this would also be the same set of circumstances under which there would be stranded capacity payments in the forward capacity market regime that currently exists in the eastern US markets.

A final very favourable property of this mechanism is that it is ideally suited to an electricity supply industry with a significant share of intermittent renewable generation capacity where the firm capacity construct makes very little sense. The firm capacity of a generation unit is the amount of energy that can be produced from a generation unit under extreme system conditions. For a thermal resource, this is a relatively well-defined concept. It is typically equal to the capacity of the unit times its availability factor. However, the amount of energy a wind unit can produce on an extremely hot high-demand day with no wind is clearly zero, and the amount of energy a solar unit can produce at dusk on an extremely hot high-demand day is close to zero. Consequently, determining the firm energy of these resources is more of a political decision than a technical engineering decision. Consequently, paying for firm capacity from these units when they are very likely not to be available during stressed system conditions is costly for consumers because they are paying for something they are not getting (firm capacity from the intermittent units) and paying for more firm

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capacity from dispatchable units to replace the firm capacity they are not getting from the intermittent units.

The regulator-mandated standardized market for long-term contracts approach to long-term resource adequacy avoids this issue by focusing on ensuring there is sufficient energy to meet demand in the future. As discussed in chapter 10 of McRae and Wolak (2106), this mechanism creates incentives for intermittent renewable resources to re-insure their forward energy sales with dispatchable thermal resources so that their forward commitment for energy in the future will be met.

VII. Conclusions

The empirical analysis presented in this paper has quantified the direct economic benefits to contestable customers since May 2015 through the end of March 2016 in the form of reduced retail electricity contract costs from the existence of a liquid futures market in Singapore. The existence of a liquid futures market allows independent retailers to enter by purchasing futures contracts and offer retail electricity contracts that compete against the offers of incumbent retailers. Because generation-owning retailers are likely to be the eventual counterparty to most of these future contracts, these futures market sales increase the quantity of fixed-price forward contract obligations that these suppliers have when they submit their offers into the short-term wholesale market. The increased fixed-price forward market obligations cause these suppliers to submit offer curves closer to their marginal cost curves, which are found to yield significantly lower wholesale prices.

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