Assessing China's Provincial Electricity Spot Market Pilot Operations: Lessons from Guangdong Province

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Keywords China power market reform; market failures; local market power; electricity spot market.

JEL Classification Q41; Q48; D61

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September 15, 2021

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1 Introduction

Aiming to boost energy efficiency and renewables via a new round of power market reform, the Central Government of China launched the "No 9 document" in 2015. The reform covers a wide range of topics, but can be summarised as "regulating the middle, opening both ends". "Middle" is a metaphor of electricity transmission and distribution companies, which are usually natural monopolies that are under government's regulation. "Ends" refers to electricity wholesale and retail markets, whose prices used to be government-set rather than market-driven.

Prior to the reform, China employed an equal allocation dispatch system, with the same type of power plants operating for (roughly) an equal number of hours regardless of their thermal efficiency and marginal costs (Wetzel and Lin, 2019). Apparently, the previous dispatch system ignored the merit order of the power system, which suggests that those with the lowest marginal costs are the first ones to be brought online to meet demand. This resulted in inefficient allocation of resources and high costs, hence the new round of reform aimed at correcting the distortion and marketising power generation.

Targeting on improving the efficiency of power generation, the Government announced its plan to reform China's electricity wholesale market. The reformed electricity wholesale market consists of three primary markets that operate in different timescales, namely the mid-to-long-term (M2L) energy market ranging from annually to multi-daily, the spot market containing day-ahead and real-time market, and the ancillary services market aiming to ensure the security of grids. As most generation volume is governed under M2L contracts, little revenue risk exists for market participants.

Among the three primary markets, spot markets are believed to be the most liquid in the future because they will be able to respond to later information such as outages and updated load and renewables forecasts. Therefore, a focal point of the wholesale market reform is to introduce a stable and reliable electricity spot market, which will substantially improve efficiency, reduce costs and lower greenhouse gas emissions.

Eight provinces (and regions) have been selected for spot markets pilot operations, including Southern China (starting from Guangdong), West Inner Mongolia, Zhejiang, Shanxi, Shandong, Fujian, Sichuan and Gansu. Among them, Guangdong has the highest GDP and consumes the greatest amount of electricity, hence would potentially be the market with the highest trading volume. In 2020, its total electricity consumption reached 693 TWh, approximately 9.2% of China's total. It is also the center of the China Southern Power Grid (CSG), one of the two state-owned electricity utility corporations. Since the release of "No. 9 document", Guangdong is leading the reform, becoming the first province to publish bidding rules and market clearing mechanisms for its electricity spot market.[1] Till June 2021, Guangdong has completed five rounds of pilot operations. Issues may arise with pilot operations, and they need to be resolved before the formal operation of the spot market.

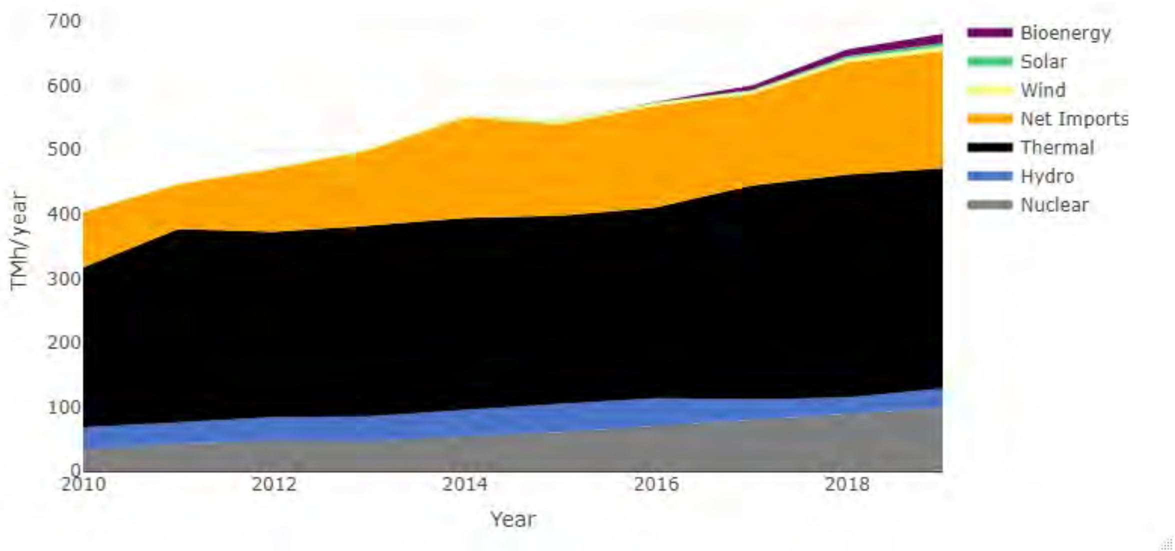
[1]See, in Chinese, http://www.gdei.gov.cn/gzhd/wsdc/myzj/201811/t20181102_130784.htm

1.1 The Guangdong power market

Guangdong is usually considered to be the province leading China's power market reform, as it is more open than other regions in terms of selecting market design choices and processes (Cao et al., 2019). Comparing with other regions, Guangdong has a high percentage of supply participating market exchanges and demand opening to retail. It is also the province with the longest functioning spot market pilot which started from September 2018.

By the end of 2020, the total installed capacity of electricity in Guangdong reached 141 GW, 65.8% of which was due to fossil fuels and 8.5% of which came from renewable energy (i.e., wind and solar) (GPEC, 2020). Figure 1 presents the generation by fuel types in Guangdong, between 2010 and 2019. Following its rapid economic development, the total electricity supply in Guangdong has been increasing steadily, with a nine-year-average annual growth rate of 6%. Despite of its share being low, the electricity generation from renewables has been twelve-folded, with an annual growth rate of 32%. Meanwhile, on average about 24% of Guangdong's electricity was imported, most of which was hydro power from Yunnan province.

Figure 1: Guangdong's Yearly Electricity Supply by Fuel Types, 2010-2019



Source: *China Energy Statistical Year Book*, 2010-2019.

Prior to the new round of power market reform, electricity generated in China was highly regulated in terms of price and quantity. Specifically, electricity was purchased by the sole grid company via an on-grid price, and was generated based on a "fair dispatch rule" (Gao and Li, 2010) – an (approximately) equal quota rule that the local government departments based upon to allocate a total power generation amount. In Guangdong in 2016, the first year of the reform, less than 8% of its electricity supply took place via market exchanges (and the rest was regulated and determined by the government), while the number reached 40% in 2020 (GPEC, 2017, 2020). Because the spot market has not yet been formally operated, all traded wholesale electricity was due to M2L contracts. The operation of the spot market, however, will allow a growing proportion of quantity to take part in the wholesale market, where generators (that participate in the market) submit bids for a specific quantity of electricity that they are willing to supply.

1.2 The Guangdong spot market pilot

Guangdong's pilot electricity spot market shares many similarities with the PJM power market (Ott, 2003; PJM, 2021), in which the market adopts a "gross pool" model, with all (participated) generation dispatched through a common pool, considering demand as given to the pool and all generators who bid into the pool bidding at their marginal cost. However, in Guangdong, not all generators participated in the market, such as renewables which were taken as a regulatory must-take, and nuclear energy which was treated as a regulatory must-run. It is also worth mentioning that imports (and exports) were not participating the spot market, as they either followed existing M2L contracts or were regulated and determined by the government (occupied 30%).

The market consists of a day-ahead market and a real-time market, which are jointly operated by the exchange centres and dispatch centres in Guangdong. The market is cleared every 15 minutes, and the clearing price is the format of locational market prices (LMPs), defined as the marginal price for energy at the location where the energy is delivered or received. Generators bid volume as well as prices, whereas customers only bid volume. After market participants submitting bids and offers, the hourly commitment schedules and the LMPs are determined. Finally, Generators are paid at LMPs, whereas customers pay a (weighted) average price of all LMPs, namely the spot market prices (SMPs).

Till June 2021, Guangdong has completed five rounds of pilot operations. Table 1 lists the characteristics and improvements of each round. To summarise, the operation period is much longer towards recent rounds – the first round of pilots only lasted for two days while the 4^{th} and 5^{th} rounds both lasted for a month. During the time, with the gradual decentralisation of the wholesale and retail markets, the total number of spot market participants is increasing. For each new round of pilots, lessons and experiences from the past are firmly learned, hence the settlement method has been improved, the information has become more transparent, and the decomposition of M2L contracts has become more liberalised.

1.3 Research scopes and contributions

In this article, we assess the efficacy of Guangdong's electricity spot market pilot operations. We aim at investigating the stability and reliability of Guangdong's spot market during pilot operations, where "stability" is reflected as the relationship between demand and prices, and "reliability" is reflected as the inefficiency of the market, measured as the

Table 1: Characteristics of Each Round of Guangdong's Spot Market Pilot Operations

Time	Characteristics and Improvements
1st round: 15-16 May 2019	190 generation units, 123 retail companies, 3 large electricity consumers participated. M2L CfDs were converted to a forward price contract, whose price equals to the thermal benchmark price plus the contracted price differences of each market entity. Due to the different on-grid tariffs approved by various types of units, the power grid company fully bore profits and losses from the M2L conversion. The retail contract signed by the retail company and its agent users remained unchanged. The unbalanced cashflow in the market generated by the pilot settlement would temporarily be paid upfront by the current medium and long-term settlement balance funds. With the spot market, M2L contracts must be decomposed to formulate the "decomposition curve". The responsibility was entirely borne by the market operating agency that determines the decomposition method.
2nd round: 20-23 June 2019	Allowed market entities to negotiate and adjust the decomposition curve independently. (The rest is the same as the first round).
3rd round: 21-27 October 2019	192 generation units, 128 retail companies, 3 large electricity consumers participated. M2L CfDs are converted into absolute price contracts. The formation of electricity tariff was based upon the wholesale prices plus the Transmission and Distribution (T&D) price. Organized and operated M2L power exchange while the spot market was in operation (between 21-27 October). The M2L contracts were decomposed based on the historical consumption of electricity users. If consensus has been made, market entities were allowed to adjust the decomposition curve, and the decomposition adjustment can be achieved through M2L transactions (while the spot market was in operation).
4th round: 1-31 August 2020	The market settlement was based upon the monthly CfD, monthly trading, spot market power exchange, and electricity contract transfers. 199 generation units, 136 retail companies, 1 large electricity consumers participated. The day-ahead market clearing results and the daily settlement bills (T+5) was published daily. The scale of electricity generation was determined according to market users' power consumption.
5th round: 1-31 May 2021	The market settlement was based upon the monthly CfD and electricity contract transfers. 209 generation units, 159 retail companies, 2 large electricity consumers participated. The day-ahead market clearing results and the daily settlement bills (T+5) was published daily. Attempted a practical capacity compensation, through no actual collection or payment was made. Carried out market-oriented demand response, though consumers were reluctant to participate.

market distortion due to a price floor, and local market power due to transfer capacity limits. We focus on the 4^{th} and 5^{th} pilots as sufficient lessons are learned from earlier pilots and both 4^{th} and 5^{th} pilots last for a month, hence (relatively) sufficient data can be collected for the econometric analysis. To the best of our knowledge, this is the first article that uses *ex-post* market data to investigate the operation of China's electricity spot market.

One of, if not, the most important parameters in the electricity spot market is the slope of the supply curve. In a perfectly competitive closed market, one would expect the supply curve following the merit order, and the competitive electricity prices equalling to the short-run marginal cost of electricity generation. Moreover, valuing the slope of the supply curve is helpful for exploring the economic impact of external shocks. For instance, the slope can tell the possible effects of increasing renewable penetrations and demand response (i.e., peak-load shaving) on electricity prices. Also, we can employ it to estimate the welfare transfer from electricity generators to consumers due to the price floor of SMPs, which is investigated in this article.

The first aim of this article is, therefore, using econometrics to estimate the relationship between total load and the SMPs. We focus on the day-ahead market because it is the main arena for trading power, and the intra-day market supplements the day-ahead market and helps secure a balance between supply and demand. One challenge is that Guangdong proposed a price floor and ceiling to the SMPs (which will be discussed further soon), hence conventional econometric methods may bias the estimates. We therefore apply censored regression analysis to estimate the supply curve. Our estimates suggest that during the 4^{th} pilot when the residual load (defined as electricity load entering the spot market power exchange) is relatively low, a 1 GW (or 1000 MW) increase in the day-ahead total load is associated with a ¥7/MWh increase in the day-ahead SMPs; whereas during the 5^{th} pilot when the residual load is high and approaches the capacity limit of the electricity system, the marginal effect raised to ¥13/MWh. The difference between the two rounds of pilots indicates a non-linear convex electricity supply curve in the Guangdong power market, hence the marginal benefit of increasing renewable penetrations and demand response can be more substantial at the current stage (when the renewable penetration is low and demand response is limited) than later (when the renewable penetration is already high and demand response has been widely applied).

As the SMPs are determined by supply and demand, market uncertainty may arise, resulting in volatile power prices. One typical example is European electricity markets such as Germany, where the rising share of renewables has made negative prices a fairly common phenomenon. Negative prices occur when a high and inflexible power generation appears simultaneously with low electricity demand, and can greatly burden the renewable surcharge. To stabilise the spot market and prevent disincentivising renewable investment, Guangdong proposed a price floor (and ceiling) to the SMPs. This, however, raises other issues such as transferring some of the consumer surplus to producer surplus due to the price floor (and the price ceiling would have the reverse effect).[2]

Our second aim is to estimate the monetary value of this welfare transfer during pilot operations. It is noteworthy that we observe no SMPs reaching the price ceiling during both rounds of pilots, and all price floors are observed during the 4^{th} round. Therefore, we focus on the welfare transfer caused by the price floor during the 4^{th} round of pilot. This is carried out by first using the earlier econometric results to estimate the day-ahead SMPs if the price floor were not implemented. Then, whenever an SMP equals to the price

[2] Given inelastic electricity demand, this will not create a deadweight loss as the price moves upward (or downward) from the equilibrium price, while the demand remains constant.

floor, for that hour the welfare transfer equals to the difference between the estimated prices and the price floor times the trading volume. Our estimates suggest that during the 4^{th} round of pilot, the welfare transfer is estimated to be ¥84 millions, or about 1.3% of the total tradable value of the day-ahead market.

Guangdong's electricity wholesale market is considered to be a moderately concentrated marketplace. During 2016-2020, 86 out of 97 local electricity generation companies participated in power exchanges, with an average Herfindahl-Hirschman Index (HHI)[3] slightly above 1,500 in month-ahead forward markets (GPEC, 2020). While the HHI might be an effective measure of system-wide market power, it gives little information about the degree of local market power.[4] Local market power arises because the existing transmission network does not provide the supplier with sufficient competition to discipline its bidding behavior into the wholesale market. Competition in the wholesale market promotes lower electricity bills for consumers, while market power tends to make electricity more expensive.

The final aim of this article is to assess the existence of local market power in Guangdong electricity market. This is done by first matching the producer-side locational market prices (LMPs) with cities in Guangdong, and then comparing the LMPs with the consumer-side SMPs. We construct an index to measure the degree of local market power, and find evidence suggesting that local market power existed in the west of Guangdong, or cities around Guangzhou and Shenzhen, the political and economic centers of Guangdong province with high electricity demand. The result suggests the necessity of investing more power lines connecting the west to the east of Guangdong.

The remaining of this article structures as follows. Section 2 reviews major literature about China's power market reform. Section 3 describes data from Guangdong's 4^{th} and 5^{th} rounds of spot market pilot operations. Section 4 gives empirical methodologies and results associated with our research scopes, and finally, Section 5 concludes and provides policy implications.

2 Literature Review

The management of China's electricity system used to be vertically integrated (Bacon and Besant-Jones, 2001), with the planning, investment and operation of the enterprises managed together by administration orders (Kahrl et al., 2013). Aiming at improving the generation efficiency of its thermal power plants, China implemented its first-round power market reform in 2003. The reform boosted the productivity of large thermal plants and

[3]HHI is calculated by squaring companies' market shares and adding up the resulting numbers. This is done to give large companies greater weight, as a large market share owned by one firm could have a negative impact on competition.

[4]See Wolak (2005) for the distinction between system-wide and local market power – "System-wide market power arises from the capacity constraints in the production and the inelasticity of the aggregate wholesale demand for electricity, ignoring the impact of the transmission network. Local market power is the direct result of the fact that all electricity must be sold through a transmission network with finite carrying capacity."[p.4]

enabled them to converge to the technological frontier (Zhao and Ma, 2013). However, Meng et al. (2016) found that a significant amount of fossil energy had been wasted due to the lack of electricity price bidding, and emphasised the necessity of electricity bidding, over-the-counter transactions,[5] and dynamic incentive mechanisms for renewable energy development.

Aiming at promoting competition in the generation and retail sectors, and setting transmission and distribution (T&D) prices based on the grids' efficient operational costs, China launched a new round of power sector reform in March 2015. Pollitt (2020) concluded that the reform has achieved a number of impressive outcomes, including the implementation of T&D prices, the marketisation of both wholesale and retail sides, and the reduction of grid companies revenue. Zheng et al. (2021) found that the reform has lowered the prices of electricity generated from thermal energy and the average retail prices, and improved thermal efficiency, but their empirical results also suggest that the reform has increased the instances of supply interruptions. Davidson and Pérez-Arriaga (2020), on the other hand, built on interviews conducted with stakeholders, to examine government plans and numerous market implementations at the provincial level. They suggested that even though market efforts may achieve efficiency gains, a stronger centralisation of market design and regulatory oversight authorities are preferred to make the market fully work.

Many literature looked at the side effects of the new found of power sector reform. Lin et al. (2019) examined the impact of market reforms on coal-fired power plants, and estimated that the existing coal generators in Guangdong had substantial outstanding debt in 2016, which creates risks for banking. They, therefore, emphasised the essence of a bilateral or centralised capacity market. Zhang et al. (2017) argued that the reform may enforce the government to attach more importance to demand-side management (DSM), motivate grid companies for DSM investment, and encourage demand response applications. Zhang et al. (2018) concerned that challenges such as the intervention from local governments in direct electricity trades and the lack of a quota system for renewable energy would potentially distort the positive impact of the reform on renewable energy integration. They argued that building up an electricity spot market would facilitate the transmission of renewable energy from western to eastern China, thereby assist the integration of renewable energy.

Literature on the China's electricity spot market is rather limited. From a cooperative game theoretic perspective, Peng and Tao (2018) found that building up a spot market could improve market competition in the electricity retailer market. Aiming at stabilising the electricity market and disciplining market power abuse, Zhang and Yan (2019) developed a market mechanism to support the collaboration between the contract and the spot market. However, to the best of our knowledge, there is no ex-post analysis on China's electricity spot market operation.

[5] Electricity users negotiate with power plants directly.

3 Data

We collect the Guangdong Electricity Spot Market pilot operations data from the Guangdong Power Exchange Center. Since there is no detailed public data available for the first and second rounds of pilot operations, and the third round only lasted for a week, we only focus on the 4^{th} and 5^{th} rounds.

The data includes the day-ahead and real-time LMPs for each node at 15-minute intervals, and the consumer-side averaged LMPs at an hourly frequency (thereafter, Spot Market Price, SMP). Everyday, the day-ahead forecast of total electricity load, baseload that do not participate the spot market,[6] local must-runs, and electricity transfer from the West (mostly Yunnan Province) and to Hong Kong are also reported at 15-minute intervals. The data also contains the actual of the aforementioned variables. Recall that because most spot market power exchanges took place in the day-ahead market, most of our empirical analysis would focus on day-ahead instead of the real-time market. Despite that, summary statistics for both day-ahead and real-time markets are given here to provide the data's full information to readers. Finally, weather data includes half-hourly temperature and wind speed in Guangdong is collected from Weather Underground[7] and is aggregated to hourly.

Table 2 gives summary statistics for the 4^{th} and 5^{th} rounds of pilots, where "Total Load" refers to the total electricity load, "Baseload" includes loads from power plants that have not yet obtained the license to directly trade with consumers, "Local Load" refers to local must-runs, "West-east Trans." refer to the electricity transfer via interconnectors from the west (i.e., Yunnan and Guizhou provinces), and "GD-HK Trans." represents the electricity transfer via interconnectors to Hong Kong. Compared with the 5^{th} round, the "West-east Trans." in the 4^{th} round pilot was much greater, while the "Must-runs" was lower, which implies that Guangdong received greater external assistance from other provinces in the 4^{th} than the 5^{th} round. It is noteworthy that the mean value of the 5^{th} round's day-ahead SMP is nearly three times than that of the 4^{th} round. During the 4^{th} round, the day-ahead SMP frequently reached the price floor of ¥70/MWh, whereas during the 5^{th} round, all day-ahead SMPs were well above the price floor, with the highest value reaching over ¥1,100/MWh, substantially greater than the maximum day-ahead SMP in the 4^{th} round. It is also noteworthy that Guangdong experienced extreme weather during the 5^{th} round of pilots – the unusually high temperature boosted electricity consumption, which is one of the main reasons for the high SMPs.[8] Finally, it is windier during the 5^{th} than the 4^{th} round.

[6] The load from power plants that are dispatched via central planning instead of market bidding.

[7] At https://www.wunderground.com/history/daily/cn/guangzhou/ZGGG/date.

[8] There are other reasons for the high SMPs in the 5^{th} round, such as the rising coal prices, increasing export due to global Covid-19 outbreak and China being the least affected major economy, and the biggest electricity generators exercising market power.

Table 2: Summary Statistics

The 4^{th} Round Pilot Operation						
Variable	Obs.	Unit	Mean	S.D.	Min.	Max.
DA Total Load	2,976	MW	96,004	14,134	63,000	123,000
DA Baseload	2,976	MW	14,004	3,253	6,883	19,501
DA Must-runs	2,976	MW	5,707	1,045	3,806	8,458
DA West-east Trans.	2,976	MW	35,981	2,487	25,008	39,118
DA GD-HK Trans.	2,976	MW	-1,888	220	-2,363	-863
DA SMP	744	¥/MWh	188.55	80.56	70.00	447.40
DA LMP	5,279,424	¥/MWh	180.35	89.92	70.00	1,500.00
RT Total Load	2,976	MW	95,094	13,707	64,682	123,125
RT Baseload	2,976	MW	14,055	3,086	7,397	20,538
RT Must-runs	2,976	MW	5,616	977	3,518	7,699
RT West-east Trans.	2,976	MW	35,954	2,369	25,049	39,794
RT GD-HK Trans.	2,976	MW	-1,770	261	-2,396	-1,042
RT SMP	744	¥/MWh	195.68	113.87	70.00	1,105.19
RT LMP	5,279,424	¥/MWh	187.85	128.67	70.00	1,500.00
Tempreture	744	F	85.26	5.13	75.00	98.00
Wind Speed	744	mph	5.45	3.06	0.00	19.00
The 5^{th} Round Pilot Operation						
Variable	Obs.	Unit	Mean	S.D.	Min.	Max.
DA Total Load	2,976	MW	100,109	17,454	49,500	122,000
DA Baseload	2,976	MW	14,292	3,330	-1,724	19,918
DA Must-runs	2,976	MW	6,994	1,123	4,208	9,859
DA West-east Trans.	2,976	MW	21,313	5,980	7,814	30,995
DA GD-HK Trans.	2,976	MW	-1,645	276	-2,334	-820
DA SMP	744	¥/MWh	527.27	155.77	171.41	1,101.25
DA LMP	5,279,424	¥/MWh	499.43	230.33	70.00	1,500.00
RT Total Load	2,976	MW	99,885	17,602	50,221	124,388
RT Baseload	2,976	MW	13,901	3,203	7,196	19,877
RT Must-runs	2,976	MW	7,095	1,206	3,773	10,282
RT West-east Trans.	2,976	MW	21,491	5,872	8,764	31,486
RT GD-HK Trans.	2,976	MW	-1,434	354	-2,392	4
RT SMP	744	¥/MWh	567.83	239.27	97.53	1497.49
RT LMP	5,604,096	¥/MWh	545.67	296.56	70.00	1,500.00
Tempreture	744	F	84.99	6.10	67.00	99.00
Wind Speed	744	mph	7.36	3.58	1.00	19.00

*DA: day-ahead; RT: real-time

4 Empirical Assessment

This section provides empirical assessments on the 4^{th} and 5^{th} rounds of Guangdong's spot market pilot operations. We first provide some stylised facts about the property of the SMPs as well as electricity load. Then, considering the fact that the SMPs were censored around the price floor of ¥70/MWh in the 4^{th} round, whereas in the 5^{th} round, all observed SMPs are higher than ¥70/MWh, we apply different regression techniques to study the relationship between SMPs and electricity load, to demonstrate the electricity supply curve. Next, because of the existence of a price floor, welfare will be transferred from consumers to electricity generators. We therefore use the results from our earlier estimated electricity supply curve to further estimate this welfare transfer. Finally, by assessing the difference among the LMPs, we demonstrate whether local market power exists in Guangdong.

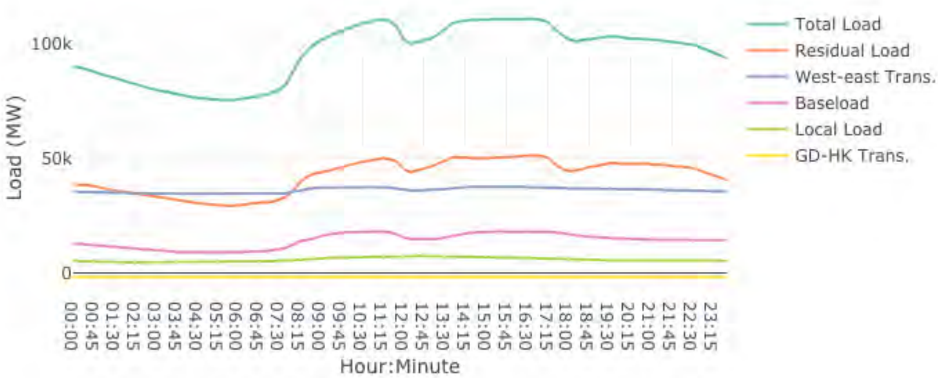
4.1 The property of spot market load and prices

Figure 2 presents the daily-average day-ahead load during the two rounds of pilots, where "Total Load", "Baseload", "Local Load", "West-east Trans.", and "GD-HK Trans." are pre-defined in Section 3. As "Baseload", "Local Load", "West-east Trans.", and "GD-HK Trans." did not participate in the spot market, we define "Residual Demand" as the remaining electricity load that participated. The total electricity load in the 5^{th} round is slightly higher than the 4^{th} round. However, as the electricity transfer from the west of Guangdong has been drastically reduced in the 5^{th} round due to its increasing electricity demand and decreasing hydro supply, the residual load in the 5^{th} round is much higher (than the 4^{th} round).

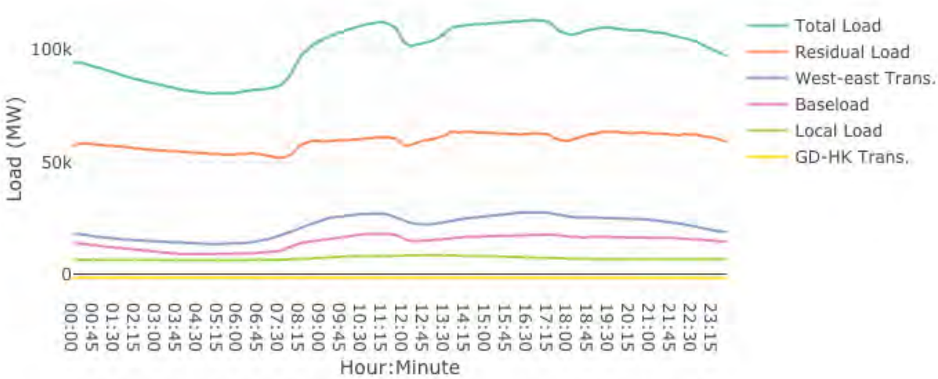
Figure 3 presents the consumer-side daily-average SMPs in both rounds of pilots. Besides the fact that the SMPs in the 5^{th} round was substantially higher than those in the 4^{th} round, one can also find that in the 4^{th} round, the SMPs during the day was substantially greater than those during the night, while this is not the case for the 5^{th} round. The main reason is that the night temperature in the 5^{th} round was high, hence air conditioners were turned on at night, resulting in high residual demand, as shown in Figure 2b. Figure 3 also compares the day-ahead with the real-time SMPs. In the 4^{th} round, the two prices were relatively close, indicating a stable round of pilot operations. However, in the 5^{th} round, the real-time SMPs were substantially greater than the day-ahead SMPs, mostly because of the unexpectedly high real-time load caused by the historically high temperature. Finally, the bars in Figure 3 represent the standard deviations of the associated SMPs. Not surprisingly, the SMPs in the 5^{th} round were more volatile than those in the 4^{th} round, and the real-time SMPs were more volatile than the day-ahead SMPs, suggesting a higher risk (for retailers) trading in the 5^{th} round than the 4^{th} round, and a higher risk trading in the real-time than the day-ahead market.

To further demonstrate the difference between the day-ahead and real-time SMPs, Figure 4 presents the dynamic of the two prices. The SMPs in the 4^{th} round appeared a stable daily seasonality, but surprisingly, in the 5^{th} round both day-ahead and real-time SMPs were heavily fluctuating with no observable seasonality. It is also noteworthy that in the 4^{th} round the comovement between day-ahead and real-time SMPs was salient, except for some particular days where the peak-hour real-time SMPs were substantially higher. However, matters changed in the 5^{th} round, where the comovement was much

Figure 2: Daily-average Day-ahead Electricity Load



(a) Daily-average Day-ahead Electricity Load, 4^{th} Round (August 2020)



(b) Daily-average Day-ahead Electricity Load, 5^{th} Round (May 2021)

Figure 3: Daily-average Spot Market Prices

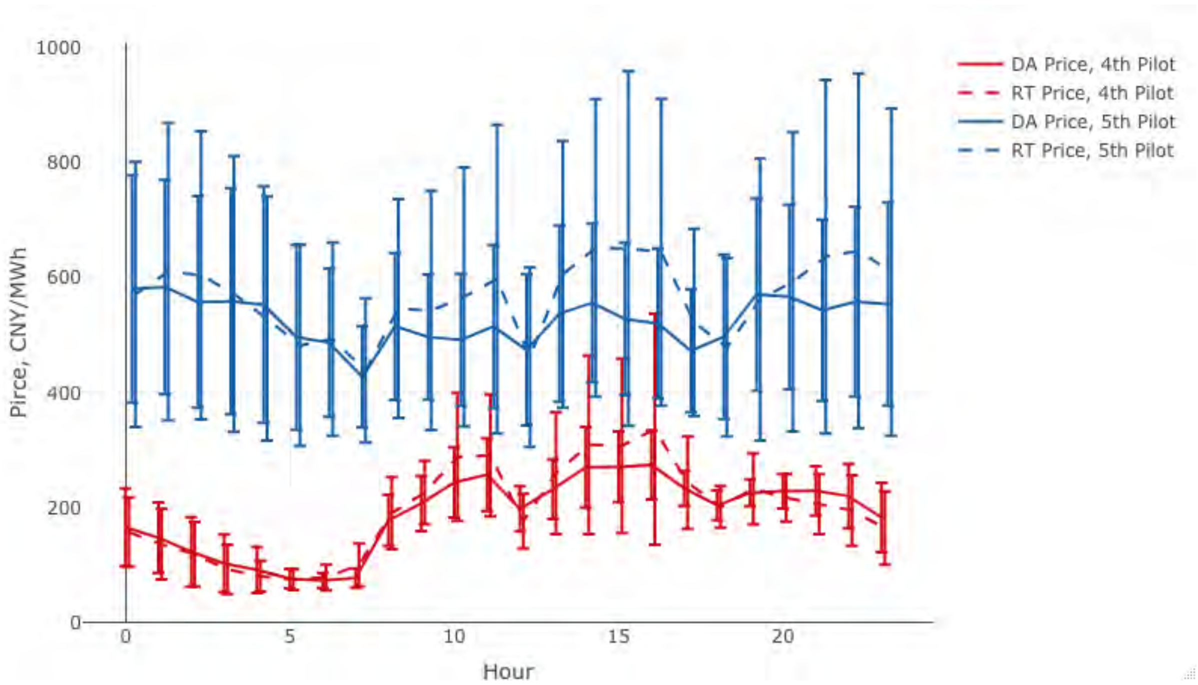
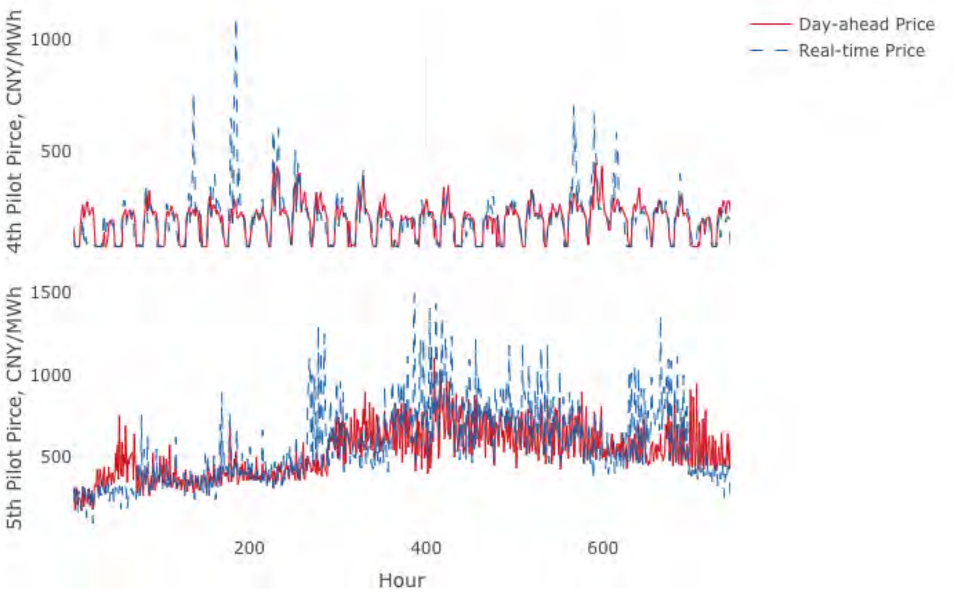


Figure 4: Day-ahead *v.s.* Real-time Spot Market Prices



weaker or even negligible, and extreme prices occurred much more frequently.

Figure 5 presents the dynamics of bidding volumes and bid-offer spreads[9] for the retailer in the monthly auctions. During August 2020, the bid-offer spread of the monthly auctions slumped to -0.13 ¥/MWh, much lower than other months. This is because market participants anticipated the SMPs to be low, resulting in a much lower monthly auction prices in August and a much lower bid-offer spread. Consequently, electricity retail companies made substantial profit in the 4^{th} round of pilots. However, this is not the case in the 5^{th} round mostly because of the heavy load that resulted in high wholesale prices (more will be discussed later in this article). Despite that, the spot market pilot operation leads to the distortion in August, and the bid-offer spread soon accommodated and returned to normal as the pilot ended.

4.2 Estimating the relationship between prices and demand

Estimating the relationship between electricity (residual) load and SMPs, namely the spot market electricity supply curve, has multiple benefits. For example, it tells how an increase in renewable energy penetration may affect the SMPs, and a high price elasticity of supply may imply the necessity of increasing the generation capacity of fossil plants in the electricity system. Another classic application of the electricity supply curve is to estimate the monetary value of welfare transfers and deadweight losses following policy changes. In a series of works, Guo and Newbery (2020, 2021) and Newbery et al. (2019) use the estimated slope coefficients of electricity supply curve to estimate the reduced deadweight loss from integrating the European electricity market, and the deadweight

[9]The bid-offer spread refers to the difference between the bid price from monthly auctions and the retail price, hence a lower bid-offer spread refers to higher retail profit.

Figure 5: Bidding Volume and Bid-offer Spread of Monthly Auctions

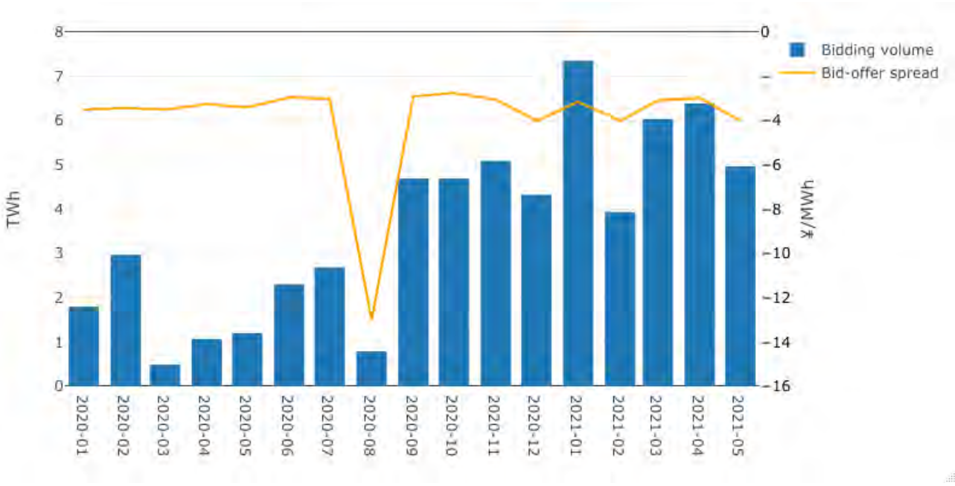
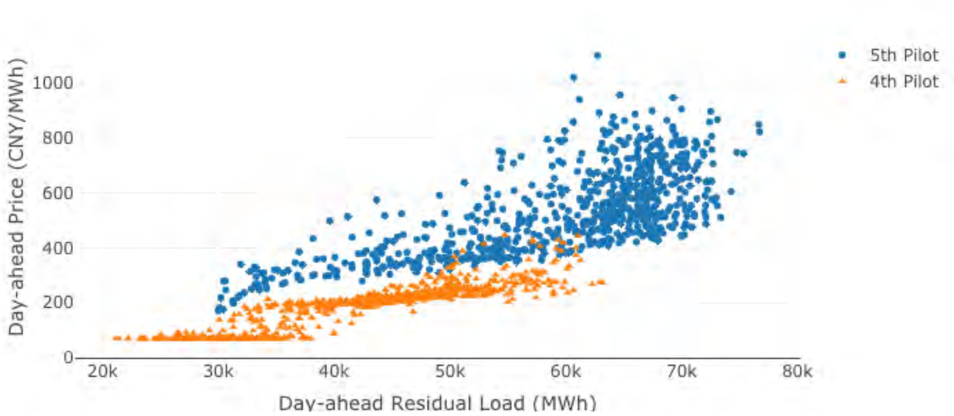


Figure 6: Day-ahead SMPs *v.s.* Residual Load



loss induced by asymmetric carbon taxes in electricity generation between Great Britain and the European Continent.

In this article, the slope of the electricity supply curve is used to estimate the welfare transfer induced by a price floor of ¥70/MWh imposed on the SMPs. Under the assumption of a vertical (i.e., inelastic) electricity demand curve, a price floor will result in a welfare transfer from consumers to electricity generators, and we estimate the monetary value of such welfare transfer during the 4^{th} round of pilot operations in Section 4.3.[10]

Figure 6 is a scatter plot showing the relationship between the day-ahead SMPs and residual load entering the day-ahead power exchange. The two rounds of pilot operations exhibit completely different market conditions, where in the 4^{th} round the day-ahead SMPs were in general in low values and frequently reached the price floor, whereas in the 5^{th} round they were high and all observed prices are well above the price floor of 70 ¥/MWh.

The price floor indicates that the SMPs are censored from below. Put another way, when the observed day-ahead SMPs are 70 CNY/MWh, without the price floor their

[10]The welfare transfer only took place in the 4^{th} round because the SMPs in the 5^{th} round was always above ¥70/MWh.

values could be lower. This means that conventional least squares methods (such as the Ordinary Least Squares, OLS) can not be applied, and neither can we remove the observations where the SMPs equal to ¥70/MWh because that will cause an omitted variables problem, resulting in biased and inconsistent estimates.

A commonly used likelihood-based model to accommodate to a censored sample is the *Tobit model* (Breen et al., 1996). Let p_i denote the censored day-ahead SMPs for hour i, and let p_i^* denote the uncensored day-ahead SMPs or the true value of p_i when the price floor is not applied. Put another way,

$$p_i = \begin{cases} 70, & \text{if } p_i^* \leq 70 \\ p_i^*, & \text{if } p_i^* > 70. \end{cases} \tag{1}$$

Then, a Tobit model for the latent variable p_i^*, which is partially observed, takes the form[11]

$$p_i^* = \beta_0 + \beta_1 d_i + \boldsymbol{\beta_2'} \boldsymbol{z_i} + \boldsymbol{\beta_3'} \boldsymbol{w_i} + \epsilon_i \tag{2}$$

$$= \boldsymbol{\beta'} \boldsymbol{x_i} + \epsilon_i, \quad \epsilon_i \sim N(0, \sigma^2) \tag{3}$$

where d_i denotes the total load for hour i, $\boldsymbol{z_i}$ is a vector containing baseload, local must-runs and interconnection transfers, all of which are expected to be negatively related to prices as they reduces tradable loads entering the spot market. All variables in $\boldsymbol{z_i}$ are pre-determined hence are exogenous. $\boldsymbol{w_i}$ is a vector including temperature and wind speed in Guangdong, which are usually believed to affect spot market prices as they directly determined electricity demand and wind generation. $\boldsymbol{\beta} = (\beta_0, \beta_1, \boldsymbol{\beta_2}, \boldsymbol{\beta_3})$ is a vector of slope coefficients, and ϵ_i is the error term. Given this, we can derive the conditional probabilities of p_i as

$$\text{Prob}(p_i = 70 | d_i) = 1 - \Phi[\boldsymbol{\beta'} \boldsymbol{x_i} / \sigma], \text{ and} \tag{4}$$

$$\text{Prob}(p_i > 70 | d_i) = \Phi[\boldsymbol{\beta'} \boldsymbol{x_i} / \sigma]. \tag{5}$$

Then, applying the Maximum Likelihood Estimation (MLE) technique, we estimate $\widehat{\boldsymbol{\beta}}_{\boldsymbol{Tobit}}$ by maximising the logarithm of

$$L(\boldsymbol{\beta}, \sigma) = \prod_{i=1}^{n} \left[\frac{1}{\sigma} \phi (\frac{p_i - \boldsymbol{\beta'} \boldsymbol{x_i}}{\sigma}) \right]^{D_i} \left[1 - \Phi (\frac{\boldsymbol{\beta'} \boldsymbol{x_i}}{\sigma}) \right]^{1 - D_i}, \tag{6}$$

where ϕ is the standard normal probability density function and Φ is the standard normal

[11] An alternative specification is

$$p_i^* = \beta_0 + \beta_1 r_i + \epsilon_i, \quad \epsilon_i \sim N(0, \sigma^2),$$

where r_i denotes the residual load. In both specifications, β_1 estimates the relationship between SMPs and the residual load because in equation (2), the estimated β_1 is conditional on baseload, local must-runs, and interconnector transfers.

cumulative distribution function. $D_i = 0$ if $p_i = 70$, and 1 otherwise. Equation (6) is the product of likelihood functions for all censored and uncensored observations.

One may also have noticed from Figure 6 that the distribution of error terms ϵ_i might be heteroskedastic, whose variance might depend on the residual demand d_i. If this is the case, we can assume $|\sigma_i| = \alpha_1 d_i + \alpha_2 d_i^2$ and replace σ by σ_i in equations (2)-(6). This technique is known as the Tobit regression with Weighted Least Squares (T-WLS) and the associated estimator can be denoted as $\widehat{\boldsymbol{\beta}}_{\boldsymbol{T-WLS}}$. Amemiya (1984) proved that Tobit model is consistent in dealing with censored dependent variables.

Quantile models, which are more robust against outliers in the response measurement, have also been established and developed to deal with censored samples (Powell, 1984, 1986). Whereas the method of least squares estimates the conditional mean of the response variable across values of the predictor variables, quantile regression estimates the conditional median (or other quantiles) of the response variable. Powell's method is known as the *Censored Quantile Regression* (CQR).

In our case, the conditional quantile functions,

$$Q_{p_i|\boldsymbol{x_i}}(\tau|\boldsymbol{x_i}) = F^{-1}(\tau) + \boldsymbol{\beta' x_i} \tag{7}$$

can be consistently estimated by

$$\widehat{\boldsymbol{\beta}}_{\boldsymbol{CQR}} = \arg\min_{\boldsymbol{\beta}} \sum_{i=1}^{n} \rho_\tau(p_i - \max\{70, \boldsymbol{\beta' x_i}\}), \tag{8}$$

where $\rho_\tau(u) = [\tau - I(u < 0)]u$ is the check function and $I(\cdot)$ is the usual indicator function. It is also noteworthy that F in equation (7) denotes the cumulative distribution function of ϵ_i, which does not have to be normal. One advantage of the CQR is, therefore, allowing for consistent estimation of the censored regression model under far less distributional assumptions than commonly required. Another advantage is also straightforward – it can distinguish among differential effects across conditional quantiles.

Table 3 presents regression results from Tobit regression, the T-WLS, and the CQR. The slope coefficients are consistent – not only among different regression techniques, but also for different quantiles of the day-ahead SMPs. On average, a 1 GW (1000 MW) increase in the total load resulted in a roughly ¥7/MWh increase in the day-ahead SMP. Not surprisingly, baseload, local must-runs, and interconnector transfers negatively affect the SMPs, as they reduce the residual load entering the spot market.[12] From the CQR results, the differences among the estimates at different quantiles are not statistically significant; therefore, we are unable to conclude that total load and other variables take different effects at different quantiles of the day-ahead SMPs. One exception is temperature, whose impact on the day-ahead SMP varies substantially at different quantiles. The day-ahead SMPs are more sensitive to temperature at higher quantiles.

[12] Although the estimated coefficients for "GD-HK Trans." are sometimes positive, they are not statistically significant.

Table 3: Regression Results for the 4^{th} Round of Pilots, Day-ahead Market

			CQR		
	(i)Tobit	(ii)T-WLS	(iii)25%	(iv)50%	(v)75%
Total load	0.0073***	0.0072***	0.0067***	0.0063***	0.0065***
	(0.0003)	(0.0003)	(0.0003)	(0.0002)	(0.0003)
Baseload	-0.0039***	-0.0041***	-0.0033**	-0.0021**	-0.0044***
	(0.0010)	(0.0011)	(0.0014)	(0.0010)	(0.0009)
Local Must-runs	-0.0086***	-0.0072***	-0.0055***	-0.0072***	-0.0104***
	(0.0017)	(0.0018)	(0.0010)	(0.0020)	(0.0016)
West-east Trans.	-0.0079***	-0.0078***	-0.0085***	-0.0072***	-0.0071***
	(0.0007)	(0.0007)	(0.0007)	(0.0006)	(0.0012)
GD-HK Trans.	0.0097	0.0116	0.0089	0.0111	-0.0029
	(0.0081)	(0.0080)	(0.0062)	(0.0100)	(0.0112)
Temperature	0.3543	0.3943*	-0.0320	0.1303	0.7225***
	(0.2382)	(0.2364)	(0.1868)	(0.1996)	(0.2564)
Wind Speed	0.0717	0.0131	0.0410	0.0471	-0.2300
	(0.4050)	(0.4311)	(0.3969)	(0.3500)	(0.2864)
Constant	-145.58***	-146.47***	-79.82***	-85.47***	-118.56***
	(27.30)	(27.67)	(25.24)	(20.28)	(21.34)
Observations	744	744	744	744	744
Pseudo R^2	0.184	0.182			

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

The next step is to estimate the slope of electricity supply during the 5^{th} round of pilot operations. For the 5^{th} round, as all day-ahead SMPs were higher than the price floor, it is not necessary to implement censored regressions; instead, we implement the uncensored version of the regression techniques employed in the 4^{th} round, namely the Ordinary Least Squares (OLS), the Wighted Least Squares (WLS), and the Quantile Regressions (QR). Table 4 presents the results, where the slope coefficients for total load is substantially greater than those in the 4^{th} round – on average, a 1 GW (1000 MW) increase in the total load resulted in a roughly ¥13/MWh increase in the day-ahead SMP. The reason might be that during the 5^{th} round, the total load is in general higher than that in the 4^{th} round; as the residual load approaches the capacity limit of electricity system, the market becomes less competitive as the number of generators than can bid into the day-ahead market becomes less. Therefore, those generators would bid some higher prices to make more profit, resulting in a steeper electricity supply curve. This argument is also verified by the QR results – the changes in the total load take a larger effect on higher quantiles of day-ahead SMPs. At the 25% quantile, a 1 GW (1000 MW) increase in the total load is only associated with a ¥10/MWh increase in the day-ahead SMP, whereas at the 75% quantile, the number raises to ¥16/MWh. With the increase of day-ahead SMP, the impact of total load on the price change becomes greater.

Similar to the 4^{th} round of pilots, baseload, local must-runs, and interconnector transfers were also negatively associated with the day-ahead SMPs. However, counter from the 4^{th} round, the QR results suggest that those effects are heterogeneous at different

Table 4: Regression Results for the 5^{th} Round of Pilots, Day-ahead Market

			QR		
	(vi)OLS	(vii)WLS	(viii)25%	(ix)50%	(x)75%
Total load	0.0136***	0.0134***	0.0103***	0.0131***	0.0160***
	(0.0004)	(0.0003)	(0.0005)	(0.0005)	(0.0006)
Baseload	-0.0136***	-0.0129***	-0.0098***	-0.0121***	-0.0150***
	(0.0020)	(0.0018)	(0.0025)	(0.0025)	(0.0032)
Local Must-runs	-0.0273***	-0.0271***	-0.0077	-0.0188***	-0.0335***
	(0.0036)	(0.0034)	(0.0050)	(0.0050)	(0.0065)
West-east Trans.	-0.0210***	-0.0210***	-0.0158***	-0.0223***	-0.0269***
	(0.0012)	(0.0012)	(0.0015)	(0.0015)	(0.0020)
GD-HK Trans.	-0.0250	-0.0300**	-0.0162	-0.0506**	-0.0478*
	(0.0166)	(0.0151)	(0.0219)	(0.0218)	(0.0287)
Temperature	-1.84**	-2.03***	-2.47**	-2.40**	-1.94
	(0.73)	(0.66)	(0.99)	(0.98)	(1.30)
Wind Speed	2.01*	1.94*	0.29	1.84	2.24
	(1.12)	(1.09)	(1.38)	(1.38)	(1.81)
Constant	76.39	89.69**	123.93*	66.69	45.81
	(46.81)	(42.15)	(65.52)	(65.14)	(85.72)
Observations	744	744	744	744	744
R^2	0.656	0.700			

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

quantile levels – in general, the effects are greater on higher quantiles. Perhaps counterintuitively, we find temperature lowered the day-ahead SMPs, whereas wind speeds raised the day-ahead SMPs. One possible reason is that extremely high SMPs occurred when the temperature happened to be low with high wind speed. In a small sample like the one we are working on, this can bias the results. As the sample size gets larger (in future rounds of pilots, or when the spot market is formally operated), the signs of the estimates might change.

4.3 Estimating the welfare transfer from the price floor

Recall that a price floor of ¥70/MWh is set on the SMPs. Given inelastic electricity demand, the price floor will unavoidably result in some welfare transfers from consumers to generators. Intuitively, suppose without the price floor the SMP would be lower than ¥70/MWh at, for example ¥65/MWh, but the price floor forces consumers to pay ¥70/MWh to generators; because the consumer demand is inelastic, consumers will not change their demand; but for each 1 MWh of electricity consumed, consumers transfer an additional ¥5 (than the equilibrium market clearing price) to generators. Put another way, the price floor would damage the welfare of consumers and benefit the generators.

To quantify the welfare transfer caused by the price floor, we will need to estimate the SMPs without the price floor and then subtract it by the price floor, which is then multiplied by the trading volume to derive the monetary value of the welfare transfer.[13] If we assume that without the price floor, the SMPs follow a normal distribution as suggested by the Tobit model (3), then it is natural to assume that the latent SMPs follow a truncated normal distribution $f(p_i^*; \bar{\mu}, \bar{\sigma}_i, -\infty, 70), \forall p_i^* \leq 70$, derived from the normally distributed p_i^* with mean $\bar{\mu}$ and variance $\bar{\sigma}_i^2$. To estimate the welfare transfer, we employ the results from T-WLS model, and use the predicted value of p_i^* as $\bar{\mu}$ and the standard deviation of the error term σ_i as $\bar{\sigma}_i$. Then, the probability density function of p_i^*, conditional on $p_i^* < 70$, can be evaluated by

$$f(p_i^*; \bar{\mu}, \bar{\sigma}_i, -\infty, 70) = \frac{1}{\bar{\sigma}_i} \frac{\phi\left(\frac{p_i^* - \bar{\mu}}{\bar{\sigma}_i}\right)}{\phi\left(\frac{70 - \bar{\mu}}{\bar{\sigma}_i}\right)}, \tag{9}$$

where $\phi(\cdot)$ is the probability function of the standard normal distribution. If we denote $\gamma \equiv (70 - \bar{\mu})/\bar{\sigma}_i$, then the conditional mean of one-sided truncated normal distribution with an upper tail of 70 is

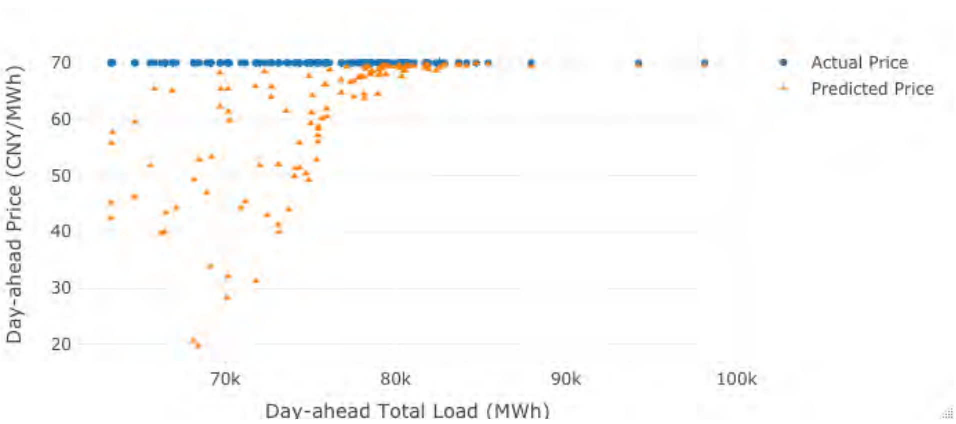
$$E(p_i^* | p_i^* \leq 70) = \bar{\mu} - \bar{\sigma}_i \frac{\phi(\gamma)}{\Phi(\gamma)}, \tag{10}$$

where $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution. Then, the welfare transfer can be estimated via the following formula

$$W = \sum_j \left[70 - E(p_j^* | p_j^* \leq 70)\right] \times r_j, \tag{11}$$

where j denotes hours when the observed SMPs equal to ¥70/MWh, and r_j denotes the residual load that enters the spot market.

Figure 7: Actual *v.s.* Predicted Day-ahead SMPs without the Price Floor, 4^{th} Round



In the 4^{th} round of pilot operations, there are 126 out of 744 hours when the day-ahead SMPs equaled to ¥70/MWh. Following the aforementioned approach, Figure 7 presents

[13] In fact, the price floor and ceiling was also applied to the LMPs. However, as we have no information about electricity load at each node, we are unable to use the LMPs to estimate the welfare transfer.

the estimated day-ahead SMPs from the Tobit-WLS regression results, if the price floor were not implemented. We can then estimate that the welfare transfer was ¥84 millions during the month, or about 1.3% of the total tradable value of the day-ahead market.

4.4 Measuring local market power

Competition sets market prices at an efficient level where necessary investments are financed and firms are provided with "incentive to reduce costs, increase efficiency, and innovative as the only means of increasing profits" (Newbery, 1995)[p.39].

In this subsection, we use the locational market price (LMP) during the 4^{th} and 5^{th} rounds of pilot operations to investigate whether local market power exists in Guangdong's electricity supply system. Local market power exists mostly due to transfer capacity limits from one node to another; in that case, if more electric grids were built and the capacity of electricity transfers increases (from the lower-price to higher-price nodes), the market would be more efficient.

By comparing the LMPs at different cities, we assess the existence of local market power, and if local market power exists, one may observe some much higher LMPs in some cities than others. Inspired by Lerner (1934), we define an index of local market power for city c during the entire month of a pilot as

$$L_c = \frac{1}{N} \sum_{i=1}^{N} I_{c,i}, \tag{12}$$

where

$$I_{c,i} = \begin{cases} (\tilde{p}_{c,i} - p_i)/\tilde{p}_{c,i} & \text{if } \tilde{p}_{c,i} > p_i \\ 0 & \text{otherwise} \end{cases}, \tag{13}$$

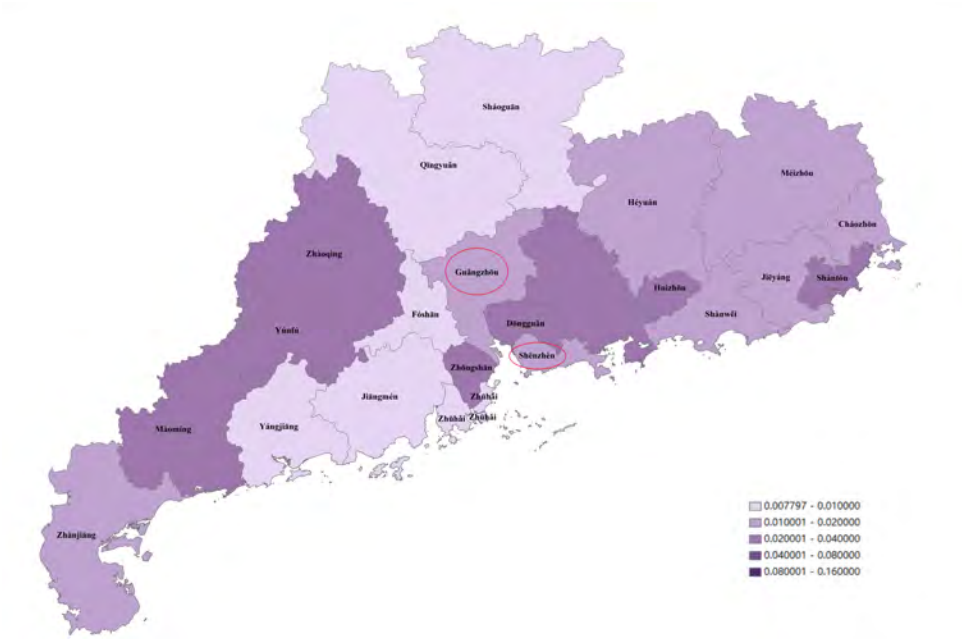
where $\tilde{p}_{c_i}$ denotes the LMP for city c at time i, and p_i is the SMP at time i.[14] Therefore, the index L_c ranges between 0 and 1. A perfectly competitive local market has $L_c = 0$, such that no local market power exists; the index approaches to 1 when the LMPs were substantially and consistently greater than the SMPs.

We then calculate L_c for each city in Guangdong. The assessment of local market power is depicted in Figure 8, with Figure 8a assessing the 4^{th} round and Figure 8b assessing the 5^{th} round. A darker color represents a greater value of the index L_c, hence more substantial local market power. Recall from Figure 4 that due to the heavier load, the SMPs in the 5^{th} round were much higher than those in the 4^{th} round, therefore it is not surprising to observe that the indices $L_c, \forall c$ are in general higher in Figure 8b than 8a.

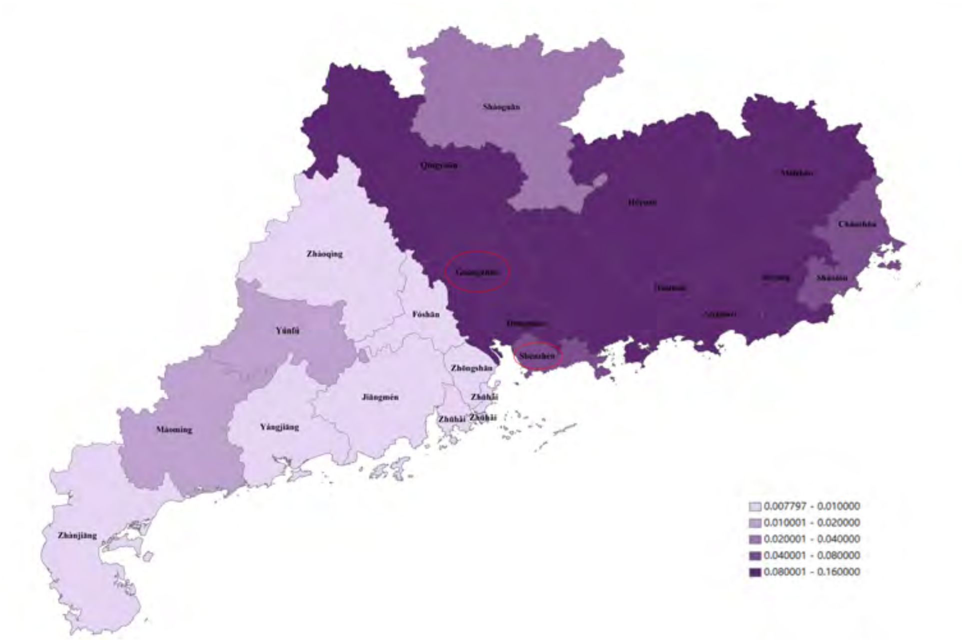
We find that cities with greater L_c, such as Huizhou, Dongguan, Zhongshan and Shantou, are located around Guangzhou and Shenzhen, the political and economic centers of Guangdong that occupied over 30% of electricity consumption in the Province.[15] The

[14] Note that there might be multiple nodes (and LMPs) within a city.
[15] Source: websites of Guangdong Statistics Department other cities' Statistics Department.

Figure 8: Local Market Power Assessment of Guangdong



(a) 4^{th} Pilot Operation

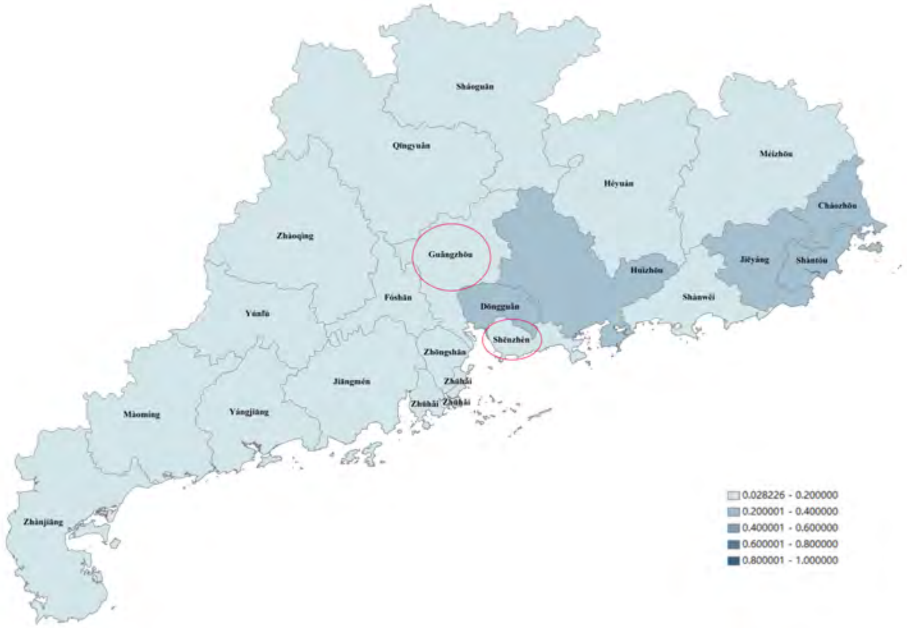


(b) 5^{th} Pilot Operation

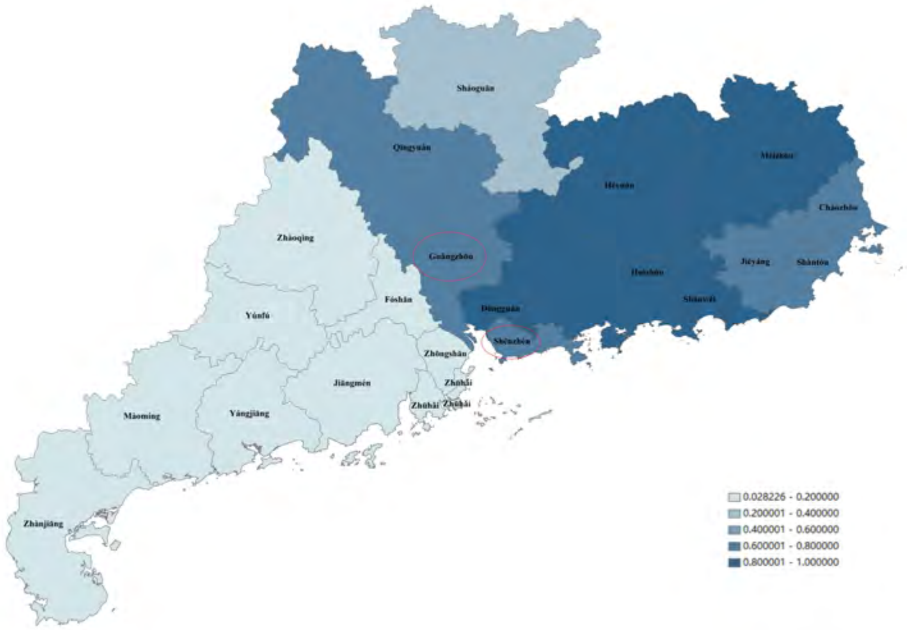
reason is simple: electricity load is transferred from those cities to Guangzhou and Shenzhen, boosting the load needed in the surrounded cities and resulting in local market powers. This argument is further supported by Figure 8b – when the load was heavy at the provincial level, much broader areas around Guangzhou and Shenzhen are affected, especially in the north-eastern cities of Guangdong which are heavily connected with Guangzhou and Shenzhen via high-voltage power lines.

To enhance the robustness of our assessment, we also use a naive method to assess

Figure 9: Local Market Power Assessment of Guangdong



(a) 4^{th} Pilot Operation



(b) 5^{th} Pilot Operation

local market power – the percentage of hours that the LMPs are greater than the SMPs. The results are presented in Figure 9, which allows us to make the same conclusion – local market power exists in cities around Guangzhou and Shenzhen, suggesting the necessity of investing more power lines connecting the west to the east of Guangdong, to achieve market efficiency. However, it is also noteworthy that a more realistic research topic might be whether the investment can be profitable, and to answer this question, further cost-benefit analysis is needed and we shall leave this to future research.

5 Conclusions and Policy Implications

China is still in the process of the power sector reform, with mid-to-long-term (M2L) power exchange in operation since 2016. The share of electricity load that took place via market exchanges has been increasing from 8% in 2016 to 40% in 2020, and the ratio is expected to be higher in the future. However, China does not yet have a formal electricity spot market, which is usually believed to be the most liquid, and if the market is competitive, the associated spot market prices should represent the short-run marginal cost of electricity generation.

Eight provinces (and regions) were selected for electricity spot market pilot operations, among which Guangdong has the highest electricity demand and is usually considered as the province leading China's power market reform. Till June 2021, Guangdong has completed five rounds of pilot operations. Lessons and experiences from the pilots should be learned, and to the best of our knowledge, this is the first article using *ex-post* data to assess the efficacy of China's electricity spot market pilot operations.

Our results suggest that during the 4^{th} and 5^{th} rounds of Guangdong's spot market pilot operations, the spot market prices (SMPs) are more volatile in the real-time than the day-ahead market, suggesting a higher risk trading in the real-time market. Due to historical high temperature, increasing coal prices, global Covid-19 outbreak while China being less affected, and a moderately concentrated wholesale market, we observe much higher SMPs in the 5^{th} than the 4^{th} round. The impact of electricity load on the day-ahead SMPs are also substantially different – during the 4^{th} round, a 1 GW increase in the total load is associated with a ¥7/MWh increase in the day-ahead SMPs, while the number increased to ¥13/MWh in the 5^{th} round. During the 4^{th} round the SMPs were frequently censoring around the price floor of the SMPs at ¥70/MWh. This indicates a welfare transfer from electricity consumers to generators, and we estimated the monetary value of the transfer to be ¥84 millions, or about 1.3% of the total tradable value of the day-ahead market. Finally, we assessed the local market power in Guangdong, and argued that under heavy load, Guangzhou and Shenzhen, the political and economic centers of Guangdong, received electricity transfers from cities around, resulting in non-negligible local market power.

Guangdong's recent attempts to operate the electricity spot market are valuable in the sense that they discovered the possible range where the SMPs will lie within. In the 4^{th} round the price floor took its effect, suggesting that without the price floor some much lower or even negative SMPs may occur. This, therefore, reflects the lowest possible prices of power generation in Guangdong. In the 5^{th} round due to multiple aforementioned reasons, electricity demand was high and the grid was stressed by hefty load, resulting in some substantially high SMPs, which may reflect the highest possible prices of power generation in Guangdong.

In Guangdong, the average Herfindahl-Hirschman Index (HHI) was above 1,500, raising concerns of large generators abusing (system-wide) market power. Evidence also shows the existence of local market power in Guangdong, especially when electricity demand approaches the capacity limit of the power system. This indicates further investment in power capacity and electricity grid is necessary. It is also suggested that further investigations on market power abuse are vitally important, and large power companies need to be further regulated.

Due to the unexpectedly high SMPs in the 5^{th} round of pilot operations, 136 out of 161 electricity retailers were making a loss participating in the spot market. The reason is simply because prior to the spot market pilot operation, retailers had already signed long-term contracts with their customers, in which the retail prices of electricity were even lower than the SMPs. As the retailers are unable to immediately pass on the wholesale cost to customers, in May 2021 the total loss for all retailers was over ¥5 billion (about 21% of total tradable value in the 5^{th} round), and one of them went bankruptcy. Because of this, the system operator decided to postpone the next round of spot market pilot operations to early 2022.

Guangdong's spot market pilot operations therefore bring us multiple lessons. First, market power needs to be firmly monitored and regulated, otherwise oligarchic conspiracy may take place and harm the benefit of small retailers. Second, the government's plan and policy need to be transparent and upfront, otherwise retailers' prior plans might be distorted and their long-term investment might be disincentivised. Third, a longer period of spot market pilot operation is desired and system operators should "let the market decide" – even though in May 2021 the retailers are losing, the hope was that if the spot market continues to operate for several months, their losses might be recovered. Finally, the price floor (and ceiling) needs to be gradually removed because a price floor harms consumers while benefits generators; on the other hand, a mechanism that can properly deal with extreme pricing is also needed to ensure the stabilisation of the market.

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