# Ontario's Auction Market for Financial Transmission Rights: An Analysis of its Efficiency

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**ABSTRACT**

Financial transmission rights (FTR) are financial products that entitle their holder to receive a payment based on the degree of congestion in a transmission system. In many liberalized electricity markets, FTR are sold at auction by the local electricity system operator. This paper addresses several questions about the performance of FTR auctions in Ontario's restructured electricity market, including whether auction market clearing prices approximate realized payouts and whether there is any evidence that the competitiveness of auctions, as measured by the number of bidders, affects the forward market unbiasedness or informational efficiency of the auctions.

The paper finds that the auction process is inefficient in the sense that market clearing prices are substantially and systematically lower than realized payouts, resulting in substantial transfers away from consumers. However, there is some evidence that the auction market is more efficient when there are three or more bidders.

**Keywords:** Electricity market; Liberalization; Financial transmission rights; Forward market unbiasedness; Informational efficiency; Auction competitiveness; Ontario

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## 1. INTRODUCTION

Spatial variation of electricity prices arises as a result of it being economically desirable to transfer more electricity from one point to another than the transmission system connecting the points is physically capable of achieving. In such an event the transmission system is said to be congested; the price will be lower upstream of the constraint and higher downstream.[1] The electricity system operator[2] that financially settles electricity transactions will pay the lower price for electricity upstream of the constraint that is transferred and sold at the higher price downstream. The

1. Strictly speaking, the price upstream of the constraint will be no greater than the price downstream. I adopt the strict inequality to ease discussion throughout the paper. Transmission line losses can also result in price variation but this is ignored throughout this paper.

2. System operators are known in different jurisdictions as an independent system operator, a regional transmission organization, or a transmission system operator.

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difference is known as congestion rent. In the event there is no congestion, there will be no spatial price variation and no congestion rent. The sum of all congestion rent is non-negative by definition and is known as the merchandizing surplus.

The ex ante uncertain nature of transmission network congestion poses a financial risk to electricity traders, which can include generators and retailers. Financial transmission rights (FTR) were developed as a mechanism to provide a payout based on the realized congestion rent associated with a specific potential constraint in the transmission network and can be used to hedge this risk; see, for instance, Hogan (1992). As a result, FTR may support a more efficient allocation of resources than would otherwise be possible: in the short-run by minimizing production costs and in the long-run by informing investment decisions. In many restructured electricity markets, FTR for various elements of the transmission network are sold by the system operator in auctions. It is by bidding in these auctions that traders can obtain the FTR necessary to hedge particular trades. Rosellón and Kristiansen (2013) provide an extensive overview of issues related to FTR.

This paper examines the performance of FTR auctions in Ontario's restructured electricity market and examines four related questions. First, do auction market clearing prices (MCP) approximate the realized payout (congestion)? Second, is there any evidence that auctions are informationally efficient in the sense that the information available at the time of the auction is accounted for by the MCP? Third, is there any evidence that the competitiveness of auctions as measured by the number of bidders impacts the forward market unbiasedness or informational efficiency of the auctions? Fourth, what policy purpose does the auction process serve?

The paper finds that over the period 2003 to 2011 FTR auction MCP were substantially lower than realized payouts. In the auctions examined herein, FTR that were sold for $152.5 million received a total payout of $328.6 million. As a result, there was a transfer of wealth away from consumers who would collectively be the residual claimants on these (in the form of reduced transmission charges) were FTR held on their behalf.

On average across all auctions observed there is mixed evidence that MCP is an unbiased forecast of payout (congestion). In auctions with at least three bidders the MCP is an unbiased forecast of the payout but when there are only one or two bidders the MCP is a biased forecast of the payout. Further, there is no evidence that information available at the time of the auction is not accounted for by the MCP.

Regarding policy purposes, there is little to support the proposition that the auction of FTR has made the Ontario market more efficient. A majority of electricity trades between Ontario and neighboring markets occur without a hedge that could be provided by an FTR and a substantial volume of FTR are procured and held by speculators not engaged in trade. Moreover, as Ontario's market has developed into one in which virtually all generation capacity therein is either under contract with or owned by government, forward-looking generation investors have no need to secure their investment with forward sales. Under these circumstances, it is unlikely that the auctioning of FTR contribute to the efficiency of the Ontario market.

The balance of the paper is organized as follows. Section 2 highlights a few important features of Ontario's market design. Section 3 defines two key types of FTR, how their realized value is related to transmission system congestion, the specifics of FTR in Ontario and New York, and summarizes some of the key literature on FTR. Section 4 sets out a framework for considering forward market unbiasedness and informational efficiency, including the role of auction competitiveness. Section 5 the data and section 6 sets out the econometric specification. Section 7 reports estimation results and section 8 concludes.

## 2. THE ONTARIO ELECTRICITY MARKET

Following a restructuring process that began in 1997 with the publication of a provincial government white paper (Ontario Ministry of Energy, Science, and Technology, 1997) and development of a comprehensive market framework (Market Design Committee, 1999), Ontario's wholesale electricity market opened to competition on May 1, 2002. The initial market design was one in which energy was exchanged at a single, internal, hourly wholesale price irrespective of internal congestion. The design also included congestion pricing and associated FTR for the interfaces with neighboring jurisdictions. Internal locational pricing was planned to be introduced after eighteen months of market operations but this never happened.

Over time, the provincial government has incorporated a number of features into the market design to drive investment in a variety of different generation technologies. Today, virtually all generation capacity in Ontario is either owned outright by the government or operates under contract with a provincial agency that shields generators from the risk associated with the hourly market conditions, including variation of the hourly wholesale price. One important consequence of this is that forward-looking generation investors have no need to secure their investment with forward sales to consumers in order to obtain project financing.[3] Beyond the FTR market there is no organized forward market for electricity in Ontario.

Notwithstanding the single, hourly internal price within Ontario, congestion can cause price variation at the interfaces of Ontario and neighboring markets. It is in relation to this aspect of the transmission network that FTR are sold by the electricity system operator, which in Ontario is called the Independent Electricity System Operator (IESO).

## 3. FINANCIAL TRANSMISSION RIGHTS

### 3.1 Nomenclature

Consider a transmission system with two nodes, A and B, that are connected by a transmission line with some positive capability to transfer electricity between the nodes. Define the prices at the respective nodes to be $p_{A,t}$ and $p_{B,t}$ at time *t*. If the line between A and B is not congested, then $p_{A,t} = p_{B,t}$ and the congestion rent is zero. If the line is congested such that flow from A to B is limited by the line's transfer capability, then $p_{A,t} < p_{B,t}$ and there is positive congestion rent in the direction A to B in the amount of $\left(p_{B,t} - p_{A,t}\right) > 0$ per unit of transfer capability. Conversely, if the line is congested such that flow from B to A is limited by the line's transfer capability, then $p_{A,t} > p_{B,t}$ and there is positive congestion rent in the direction B to A in the amount of $\left(p_{A,t} - p_{B,t}\right) > 0$. A particular line cannot be congested in both directions simultaneously. Of course, real transmission systems have many nodes and many lines connecting certain pairs of them.

3. For instance, contracts that pay generators a fixed price for their energy and environmental attributes, that may be structured as a contract-for-difference based on the hourly wholesale price, remove the risk associated with the hourly market conditions. Contracts of this type are common for renewable energy generators in Ontario (and elsewhere). Other contracts that provide fixed monthly capacity payments, with deductions equal to the amount by which the hourly wholesale price exceeds a contractually-specified marginal cost, also remove the risk associated with the hourly market conditions as long as the generator produces electricity when the hourly wholesale price is sufficiently high. Contracts of this type are common for natural gas-fired generators in Ontario. For additional details on these and other characteristics of the Ontario electricity market, see Rivard and Yatchew (2016).

### 3.2 Definition of a Financial Transmission Right: Obligations and Options

An FTR is an instrument that entitles its holder to receive a payout based on the state of congestion on a particular element of the transmission network, say the line that connects node A and node B. A one-megawatt FTR is defined based on the direction of the right—that is, from a source to a sink (say, node A to node B)—and the period of time during which it is valid. Typical validity periods are one year and one month.

The payout to the holder of an FTR is based on the relevant congestion rent and is typically structured as either an obligation or an option. For an FTR obligation from A to B, the payout is defined as the price at node B (the sink) less the price at node A (the source), summed across all the hours during which the right is valid. Mathematically:

$$\textit{Obligation Payout}_{A\ to\ B,\ \underline{T}\ to\ \overline{T}} = \sum_{t=\underline{T}}^{t=\overline{T}} \left(p_{B,t} - p_{A,t}\right) \tag{1}$$

An FTR obligation's total payout may be positive, negative, or zero because the sink node price may be greater than, less than, or equal to the source node price in each hour, and so the contribution to the payout in each hour of the validity period may be positive, negative, or zero. Note that an FTR obligation from B to A that is valid for the same period has a payout with an identical magnitude but the opposite sign.

For an FTR option from A to B, the payout is defined similarly except that the hourly contribution is non-negative. Mathematically:

$$\textit{Option Payout}_{A\ to\ B,\ \underline{T}\ to\ \overline{T}} = \sum_{t=\underline{T}}^{t=\overline{T}} \max\left(p_{B,t} - p_{A,t}, 0\right) \tag{2}$$

An FTR option's total payout is non-negative by construction because the contribution to payout in each hour of the validity period is non-negative. Note that an FTR option from B to A that is valid for the same period has, in general, an unrelated payout.

Since the payout associated with an FTR obligation may be negative, the market clearing price may be negative (in which case, the holder would be paid to hold the obligation). Whether this happens depends on the nature of this risk; that is, whether it is likely enough that the holder would have to make a sufficiently large payment so to make the expected payout of the obligation negative. Since the payout associated with an FTR option is non-negative, holders need not ever be paid to hold an FTR option. As such, the holder of an obligation faces additional risk compared to the holder of an option. One would expect that the additional risk would mean that obligations would have lower market clearing prices than options.

One potential role for FTR is to act as a hedge against uncertain congestion costs. If a trader has scheduled a given amount of electricity to flow from node A to node B and holds the same quantity of the associated FTR obligations, the FTR obligation would perfectly hedge the uncertain congestion cost associated with the lines that connect node A to node B. Note that an FTR obligation can be decomposed into two parts that are priced in relation to the price at a system hub.[4] Many liberalized electricity markets, including New York, use FTR obligations.

Regarding FTR options (on which the holder does not make a payout when the relevant price difference is negative), Hogan (2013) states that "[t]his financial contract might be more attrac-

4. That is, for hour *t* (ignoring the time subscript for simplicity), $p_B - p_A = \left(p_B - p_{HUB}\right) + \left(p_{HUB} - p_A\right)$. Decomposability facilitates the development of trading at the hub because trades between other nodes can be priced in relation to it.

tive as a tool for hedging purposes, and it is typically the first suggestion from market participants" (p. 33) and "[t]he option might also be more valuable for speculators who want to trade rights but do not plan to match the FTR with a schedule [trade]" (p. 33). However, note that an FTR option cannot be decomposed into two parts that are priced in relation to the price at a system hub.[5] In Ontario, all FTR are options.

### 3.3 Financial Transmission Rights in Ontario

FTR in Ontario are valid for two durations: one year and one month. One year duration, so-called long-term, FTR are sold on a quarterly basis in a two-round auction; in particular, auctions of FTR valid over quarters *q*, *q+1*, *q+2*, and *q+3* are conducted in two rounds in the second month of quarter *q-1*, with 25 percent of available FTR sold in the first round and the remaining in the second round. One month duration, so-called short-term, FTR are sold on a monthly basis in a one-round auction; in particular, auctions of FTR valid in month *m* are held in month *m-1*. All FTR are for 1 MW of transfer capability.

Prospective FTR purchasers submit, independently on a path-by-path basis, sealed bids to the IESO, which conducts all auctions. All bids are required to have strictly positive bid prices. The number of FTR created by the IESO for each path is related to the physical transmission capacity anticipated to be available on that path.[6] Each auction MCP is determined, independently on a path-by-path basis, as the bid price of the last accepted bid.

As noted above, in Ontario FTR are available on all its transmission interfaces with its neighbors. The jurisdictions neighboring Ontario are Manitoba, Minnesota, Michigan, New York, and Quebec. As discussed further below, the analysis reported in this paper is limited to consideration of interfaces with Minnesota, Michigan, and New York. For each export-oriented path, node A is Ontario, while for each import-oriented path, node B is Ontario. In each case, the other node is the relevant external jurisdiction.

Demand to hold FTR arises from two main sources: hedging and speculation. As discussed above, traders can buy FTR to hedge the uncertain cost of transmission congestion; speculators buy FTR to profit from the potential for the payout associated with realized congestion being greater than the auction MCP. Both types of buyers may buy individual FTR or portfolios.

5. That is, for hour *t* (again ignoring the time subscript), $\max(p_B - p_A, 0) \neq \max(p_B - p_{HUB}, 0) + \max(p_{HUB} - p_A, 0)$.

6. The total payout to all FTR on a particular path is the relevant price difference multiplied by the number of FTR that were created by the system operator. The total congestion rent collected on a particular path is the relevant price difference multiplied by the realized amount of electricity transferred on the path. The number of FTR is selected before both the auction and the amount of electricity transferred is realized. To the extent that the former is an unbiased estimate of the latter, total payout and total congestion rent will be approximately equal. However, to the extent that FTR are created in systematically greater numbers than realized ability to transfer electricity, the total payout will systematically exceed the total congestion rent. Without another source of revenue, this is not a financially feasible condition for the system operator to sustain. In effect, this imposes a budget constraint on the system operator's selection of the number of FTR that requires it to anticipate future transmission system conditions. As such, the number of FTR created for a particular path is related to the physical transmission capacity anticipated to be available on that path. Note that rather than being solved on a path-by-path basis, in practice this problem is solved simultaneously for all paths and is often referred to as the simultaneous feasibility test. In Ontario, the creation and auction of FTR, as well as the implementation of the simultaneous feasibility test, is governed by chapter 8 of the IESO Market Rules; for the current Market Rules, see IESO (2017).

### 3.4 Existing Assessments of FTR Auctions in Ontario

Ontario's FTR market has not received significant analytical attention. The Market Surveillance Panel (Panel) (2010) conducted a simple statistical and descriptive analysis that compared the auction MCP directly to realized congestion rent for the period May 2002 to February 2010 and concluded that MCP was neither unbiased nor informationally efficient in its prediction of congestion. The term informational efficiency is discussed in more detail in section 4.

The Panel found that, over the period from May 2003 to April 2010, purely financial market participants (those who had not scheduled any exports from or imports to Ontario) purchased 23 percent of all FTR during the period June 2002 to March 2010, while 64 percent of all scheduled exports from or imports to Ontario occurred without the trader possessing an FTR. This led the Panel to conclude that "physical intertie transactions are typically divorced from [FTR] ownership."

The Panel recognized that "even if [FTR] were not used for hedging purposes financial participants could play an important role is the price discovery process, thereby enhancing information brought to the market and improving the market efficiency." Based in part on the fact that generation investment in Ontario is centrally planned, however, the subsequent conclusion drawn was that "it does not appear this theoretical benefit has materialized in Ontario's [FTR] market."

More recently, IESO (2013) investigated whether changes in the number of FTR offered for sale as a result of rule changes in 2004 that resulted in the use of some FTR auction revenue to fund the sale of additional FTR, with the intent of inducing additional participation in FTR auctions and therefore additional competition and enhanced reliability, had the effect of attracting additional bidders to FTR auctions.[7] The report found that increases in the number of FTR offered for sale did not attract additional bidders on the interfaces concerned and took this to imply that there is "no correlation between [FTR] availability and competition in energy trade." It is well to note, however, that the number of market participants registered to participate in FTR auctions did increase from 18 in 2003 to 25 in 2011, possibly in response to the observed profitability of FTR purchases.

### 3.5 Assessment of FTR Auctions in Other Jurisdictions

Beyond Ontario, the New York FTR has been studied in the literature. New York FTR differ from those in Ontario as they are obligations rather than options. As such, the payout associated with a given FTR may be expected to be negative. This possibility means that negative auction MCP must be possible as well. This is because there is no guarantee that auctions will clear at a strictly positive price. Siddiqui et al (2005) provide an early study of the New York market which focused attention on the performance of six-month-duration FTR sold at the first four auctions over the years 2000 to 2001. The study was not econometric in nature, but instead directly compared MCP to payouts. Specific transmission paths were considered independently and were further distinguished based on the sign of the MCP. The authors conclude the FTR market generally predicts the direction of congestion on a given transmission line, suggesting a certain degree of informational efficiency. However, they also found that the magnitude of payouts generally exceeded the magnitude of MCP, with the result that FTR were systematically profitable for traders.

Hadsell and Shawky (2009) analysed New York FTR data over a two-year period beginning in spring 2006. The path-specific nature of the FTR is ignored and, unlike in Siddiqui et al (2005), no distinction is drawn between FTR characterised by positive or negative MCP. The results

7. Following the release of IESO (2013) the 2004 rule changes have been revisited to avoid this use of auction revenue.

indicated that for one-month FTR the marginal effect of a change of MCP on congestion diverges significantly from one, both above and below. With respect to six-month and one-year FTR, the results indicated that a positive and significant portion of the payout was not explained by the variation of MCP. Specifically, regarding the auctions that occurred in spring 2006 and spring 2007, the results indicate that across auctions of all durations the average returns to holding FTR were 25 and 30 percent, respectively. Regarding only those FTR with 12-month durations, which is the duration focused on in this paper as discussed below, the average returns of auctions held in spring 2006 and spring 2007 were –11 and 41 percent, respectively.[8] In this context, the term 'return' means the percentage gain from buying in the forward market (at the auction MCP) and settling in the spot market (realized congestion or payout). Taken together, the results indicate a lack of informational efficiency in the New York FTR market in the form of its ability to predict congestion, as well substantial profitability to holding FTR.

## 4. FORWARD MARKET UNBIASEDNESS AND INFORMATIONAL EFFICIENCY

### 4.1 Forward Market Unbiasedness Hypothesis

A forward market price is said to be an unbiased predictor of the spot price if, in the long run, there is a one-for-one relationship between forward and spot prices and no systematic difference of levels. This is a strong hypothesis about the information efficiency of the forward market. A weaker formulation of this hypothesis is that there is a one-for-one relationship between forward and spot prices with allowance for a systematic difference of levels. Specified as such, the strong hypothesis implies the weak but not the converse.

Assuming transaction costs are zero and economic agents are risk neutral, under the strong hypothesis the *k*-period-ahead forward price in period *t*, $f_t$, is an unbiased predictor of the *k*-period ahead spot price, $s_{t+k}$. The integer *k* can be interpreted as the forecast interval. Symbolically:

$$E\left[s_{t+k} \mid \Phi_t\right] = f_{t,k} \tag{3}$$

where $E\left[\cdot \mid \Phi_t\right]$ is an expectation conditioned on the information set at period *t*. Deviations from equation (3) would be eliminated by arbitrage. Following Hodgson, Linton, and Vorkink (2004), the *k*-period-ahead linear regression equation that characterises the long-run relationship between forward and spot prices associated with equation (3) is:[9]

$$\ln\left(s_{t+k}\right) = \alpha_0 + \alpha_1 \ln\left(f_{t,k}\right) + \epsilon_{t,k} \tag{4}$$

Testing the strong version of the forward unbiasedness hypothesis using equation (4) amounts to testing the null hypothesis:

$$H_0 : \left(\alpha_0,\ \alpha_1\right) = \left(0, 1\right) \tag{5}$$

against the general alternative. Under the strong null, a one percent increase in the forward price is associated with a one percent increase in the spot price $(\alpha_1 = 1)$ and there is no systematic level

8. Calculated by the author from Table 1 in Hadsell and Shawky (2009).

9. Let $\ln\left(\mathrm{a}\right) = \alpha_0$ where a > 0 and let $\ln\left(\omega_{t,k}\right) = \epsilon_{t,k}$. Then equation (4) implies that $\ln\left(s_{t+k}\right) = \ln\left(a f_{t,k}^{\alpha_1} \omega_{t,k}\right) \Leftrightarrow s_{t+k} = a f_{t,k}^{\alpha_1} \omega_{t,k}$.

difference between the two prices $(\alpha_0 = 0)$.[10] Testing the weak version of the forward unbiasedness hypothesis using equation (4) amounts to testing the less restrictive null hypothesis:

$$H_0 : \alpha_1 = 1 \tag{6}$$

against the general alternative. A level difference is permitted because no restrictions are imposed on $\alpha_0$.[11]

### 4.2 Informational Efficiency Hypothesis

Under the null hypothesis of informational efficiency, no information available at the time of the auction can explain the variation of the period *t+k* spot price as all of this information is accounted for in the forward price, which is then said to be informationally efficient. If information available at the time of the auction is statistically significant in explaining the variation of the spot price, then the effect of this information is not accounted for in the forward price and the forward price is said to be informationally inefficient.

Equation (4) can be augmented to include a vector of additional variables, $\boldsymbol{X}$:

$$\ln\left(s_{t+k}\right) = \alpha_0 + \alpha_1 \ln\left(f_{t,k}\right) + \boldsymbol{X}_t'\boldsymbol{\theta} + \upsilon_{t,k} \tag{7}$$

Following , for example Keane and Runkle (1990), testing the informational efficiency hypothesis amounts to testing whether the additional variables do not explain any of the variation of the spot price and are therefore orthogonal to the error term in equation (7); that is, testing the null hypothesis:

$$H_0 : \boldsymbol{\theta} = \boldsymbol{0} \tag{8}$$

against the general alternative.

### 4.3 Auction Competitiveness

In the context of the framework set out above, the potential benefits of greater competition in the auction market are a greater likelihood that any given auction will yield a forward price that is an unbiased predictor of the spot price and greater informational efficiency. It is a fairly general result in auction theory that the presence of additional bidders results in more competitive auctions.[12]

A simple measure of the competitiveness of an auction is the number of bidders that participate in the auction. The null hypotheses given by equations (5), (6), and (8) can be tested using all auctions or subsets based on the number of bidders. If greater competition, measured by the number of bidders, results in a biased forward price becoming less so or greater informational efficiency,

10. Note that $\alpha_0 = 0 \Leftrightarrow a = 1$; see previous footnote. Therefore, the strong null given by equation (5) implies that $s_{t+k} = af_{t,k}^{\alpha_1}\omega_{t,k} = 1f_{t,k}^{1}\omega_{t,k} = f_{t,k}\omega_{t,k} \Rightarrow E\left[s_{t+k} \mid \Phi_t\right] = f_{t,k}$. That is, equation (3) holds precisely under the strong null.

11. The weak null given by equation (6) implies that $s_{t+k} = af_{t,k}^{\alpha_1}\omega_{t,k} = af_{t,k}^{1}\omega_{t,k} = af_{t,k}\omega_{t,k} \Rightarrow E\left[s_{t+k} \mid \Phi_t\right] = af_{t,k}$. The weak null implies that the ratio of the expected spot price and the forward price is a fixed value, $a > 0$. The strong null then holds in the special case where $a = 0$.

12. See, for instance, Holt (1980) and OECD (2006), p.32.

**Table 1: Summary Statistics for Payout and MCP**

| Sink | Source | N | Mean | Std. Dev. | Skew. | Kurt. | Min. | Max. |
|---|---|---|---|---|---|---|---|---|
| **Payout** | | | | | | | | |
| **All paths** | | 143 | 12,351.67 | 15,369.76 | 1.77 | 6.02 | 0.00 | 72,793.44 |
| **Michigan** | **Ontario** | 25 | 12,351.10 | 11,777.27 | 0.46 | 1.73 | 0.10 | 32,917.78 |
| **Minnesota** | **Ontario** | 24 | 25,272.68 | 22,239.67 | 0.81 | 2.39 | 1,800.71 | 72,793.44 |
| **New York** | **Ontario** | 25 | 4,590.95 | 9,112.80 | 3.79 | 17.57 | 0.00 | 45,448.33 |
| **Ontario** | **Michigan** | 23 | 5,554.36 | 9,279.06 | 1.62 | 4.06 | 0.00 | 28,577.55 |
| **Ontario** | **Minnesota** | 23 | 11,163.04 | 11,630.49 | 0.80 | 2.31 | 0.00 | 35,220.91 |
| **Ontario** | **New York** | 23 | 15,284.81 | 15,331.23 | 1.83 | 5.65 | 787.07 | 58,019.82 |
| **MCP** | | | | | | | | |
| **All paths** | | 143 | 6,054.06 | 7,604.73 | 2.22 | 8.26 | 44.00 | 37,385.84 |
| **Michigan** | **Ontario** | 25 | 8,303.92 | 7,276.84 | 0.75 | 2.76 | 288.00 | 27,000.00 |
| **Minnesota** | **Ontario** | 24 | 13,287.99 | 11,787.07 | 1.01 | 2.57 | 750.00 | 37,385.84 |
| **New York** | **Ontario** | 25 | 2,939.73 | 2,757.36 | 1.02 | 3.17 | 175.20 | 9,000.00 |
| **Ontario** | **Michigan** | 23 | 1,336.32 | 2,297.96 | 2.75 | 10.20 | 44.00 | 9,986.40 |
| **Ontario** | **Minnesota** | 23 | 2,886.41 | 3,029.16 | 1.92 | 6.96 | 154.00 | 13,227.64 |
| **Ontario** | **New York** | 23 | 7,330.62 | 6,179.62 | 2.10 | 8.92 | 323.00 | 29,959.20 |

then the relevant null hypotheses will be more likely to be rejected when the number of bidders is relatively small and less likely to be rejected when the number of bidders is relatively high.

## 5. DATA

### 5.1 Study Period and Paths Considered

The study period is July 2002 to December 2010, inclusive; a period of 34 consecutive calendar quarters.[13] Only long-term (annual) FTR are considered. Each long-term FTR is valid for all hours of four consecutive quarters, meaning the study period contain 31 overlapping annual periods.

There are 17 distinct transmission paths connecting Ontario's transmission network with neighboring jurisdictions. In particular, with respect to Ontario there are eight paths to and from Manitoba, Michigan, Minnesota, and New York, as well as nine paths between Ontario and Quebec. As discussed further in Olmstead (2012), the governments of Manitoba and Quebec maintain vertically-integrated, government-owned enterprises in their electricity industries and lack the competitive wholesale electricity markets that exist in Michigan, Minnesota, and New York. The absence of competitive wholesale electricity markets—and therefore competitively-determined wholesale market prices—in Manitoba and Quebec diminishes the role of traders in arbitraging spatial price variation between Ontario and these jurisdictions (to capture congestion rent) and therefore diminishes participation by traders in the associated FTR auction markets. As a result, attention in this paper is focused on the six paths that connect Ontario with jurisdictions that also have competitive wholesale markets: Michigan, Minnesota, and New York.

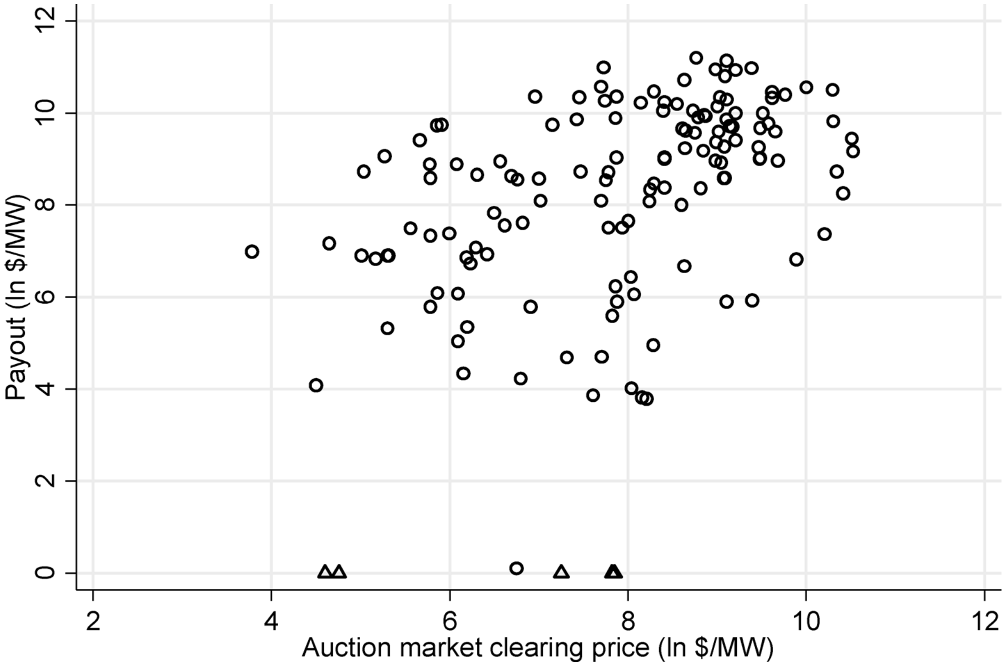
For each path there are quarters during which no FTR were auctioned; this occurs when all anticipated transmission capacity was previously auctioned. In total, there are 143 auctions for (annual) FTR. The mean number of FTR sold was 232, totalling 33,230 across all auctions and ranging from a minimum of 18 to a maximum of 991 in any individual auction.

### 5.2 Auction Results and the Number of Bidders

Summary statistics for payout and MCP are reported in Table 1. The reported MCP is the quantity-weighted average of the MCP from the two auction rounds. The mean all-paths payout is

13. See section 3 for discussion of some changes to the FTR market that occurred after the study period.

**Figure 1: Auction Market Clearing Price and Payout ($/MW in natural logarithms)**




Note: Observations with payout > $0 are illustrated as circles; those with payout = $0 are illustrated as triangles.

greater than double the mean all-paths MCP, while mean payout exceeds mean MCP and is more variable on all paths and the data exhibit significant right-skewing. The payout and MCP data are illustrated in Figure 1.

The revenue collected from all 143 FTR auctions totalled $152.5 million, while the total payout to the successful bidders totalled $328.6 million.[14] This yielded the successful bidders a total profit of $176.1 million; an average rate of return of approximately 115 percent. This value is materially greater than the returns found by Hadsell and Shawky (2009) in relation to New York's FTR market which were, as was discussed above, –11 and 40 percent for auctions of 12-month duration FTR auctioned in spring 2006 and spring 2007, respectively.[15]

Table 2 reports statistics regarding the number of bidders that contested each of the 143 auctions In each auction there were between 1 and 7 bidders, with a median of three. Also reported is the mean total auction revenue (from the sale of all FTR auctioned) and payout for (i) all bidders, (ii) each distinct the number of bidders, and (iii) several bespoke sets that each contains at least 30 observations. Aside from the two auctions with seven bidders, the ratio of payout-to-revenue exceeded unity indicating that the average payout exceeded average revenue. The ratio is generally decreasing in the number of bidders.

14. The total auction revenue and payout values are the auction count multiplied by, respectively, the mean total auction revenue and payout that are reported in Table 2.

15. Compared to the returns associated with buying forward electricity contracts and settling at the realized pool price, the average level of the returns associated with FTR in Ontario are starkly greater. For example, Botterud, Kristiansen, and Llic (2009) find that, using 11 years of data from the Nord Pool electricity market, forward prices tend to be higher than spot prices, indicating a negative return to buying in the forward market and settling at the spot price. More recent analyses by the (Alberta) Market Surveillance Administrator have identified similar outcomes in the Alberta market, where forward electricity contracts tend to trade at levels above realized spot prices. See Market Surveillance Administrator (2015), p. 9.

**Table 2: Auction Count and Mean Total Auction Revenue and Payout by Number of Bidders**

| Number of bidders | Auction count | Mean total auction revenue | Mean total payout | Payout-to-revenue ratio |
|---|---|---|---|---|
| Any (1 to 7) | 143 | 1,066,282 | 2,297,834 | 2.15 |
| 1 | 10 | 751,990 | 2,456,143 | 3.27 |
| 2 | 60 | 477,617 | 1,153,146 | 2.41 |
| 3 | 33 | 1,350,496 | 2,686,008 | 1.99 |
| 4 | 20 | 1,645,089 | 2,160,809 | 1.31 |
| 5 | 12 | 2,192,593 | 3,527,312 | 1.61 |
| 6 | 6 | 1,865,166 | 9,904,570 | 5.31 |
| 7 | 2 | 665,603 | 615,228 | 0.92 |
| 1 or 2 | 70 | 516,813 | 1,339,289 | 2.59 |
| 2 | 60 | 477,617 | 1,153,146 | 2.41 |
| 3 | 33 | 1,350,496 | 2,686,008 | 1.99 |
| 4 or 5 | 32 | 1,850,403 | 2,673,247 | 1.44 |
| 4 to 7 | 40 | 1,793,378 | 3,655,045 | 2.04 |

**Table 3: Incidence of Censoring and Assessment of Stationarity**

| Source | Sink | N | Number censored | Prop. censored | DFGLS (Tau-stat) | Zivot-Andrews | | Result |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Min t-stat | Break | |
| All paths | | 143 | 5 | 0.035 | — | — | — | — |
| Michigan | Ontario | 25 | 0 | 0.000 | –2.256 | –8.18*** | 15 | Stat. w Break |
| Minnesota | Ontario | 24 | 0 | 0.000 | –2.127 | –6.27*** | 15 | Stat. w Break |
| New York | Ontario | 25 | 1 | 0.040 | –0.963 | –17.09*** | 29 | Stat. w Break |
| Ontario | Michigan | 23 | 3 | 0.130 | –1.784 | –7.13*** | 24 | Stat. w Break |
| Ontario | Minnesota | 23 | 1 | 0.043 | –6.334*** | — | — | Stat. |
| Ontario | New York | 23 | 0 | 0.000 | –3.231* | –5.87*** | 24 | Stat. w Break |

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. "Stat." means stationary without a break; "Stat. w Break" means stationary if a break is allowed; and UR means there is a unit root even if a single break is allowed.

Auction MCP and payout data are published in IESO (various dates). The number of bidders that contest each auction was provided to the author in confidence by the IESO.

## 5.3 Incidence of Censoring and Stationarity

As reported in Table 3, payout was $0 in five of the 143 auctions. To allow use of a logarithmic transformation of payout in the regression model that follows, $1 is added to each observed payout.

Under the null hypothesis of unbiasedness, assessment of stationarity focuses on the properties of the payout time series because there are no missing observations. Table 3 reports results of the application of two unit root tests, one that allows for structural breaks and another that does not, to establish the stationarity properties of FTR. A standard unit root test—a modified Dickey-Fuller test (DFGLS)—is applied to each series.[16] If the DFGLS test implies a unit root, the Zivot and Andrews (1992) (ZA) procedure which allows for a single structural break is implemented. If the DFGLS test implies stationarity, allowance for breaks is unnecessary and ZA test is not reported. All six paths are characterised by stationary payout series, five of them once allowing for structural breaks; one series possess a unit root irrespective of whether a structural break is permitted.

16. The test is modified in the sense that the time series is transformed by GLS regression. The maximum number of lags, k, is determined by the Schwert (1989) criterion in which $k = \{12 * ((T+1)/100)^\wedge(0.25)\} = 9$ for this time series. The optimal lag length is determined by the Ng and Perron (1995) sequential t-test.

**Table 4: Summary Statistics for Explanatory Variables**

| Variable | N | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Natural gas price | 31 | 6.80 | 1.75 | 3.67 | 11.68 |
| Risk-free interest rate | 31 | 2.60 | 1.17 | 0.12 | 4.20 |

### 5.4 Additional Explanatory Variables

To test for informational efficiency, equation (4) was augmented with additional variables to obtain equation (7). While a number of variables are potential candidates for inclusion, the financial nature of FTR and the importance of natural gas prices to the determination of marginal cost suggest that interest rates and fuel costs may be particularly useful to consider whether they can explain statistically significant variation of the spot price.

In particular, variation in natural gas prices may, by impacting the marginal cost of electricity generation, instigate changes in power flows and the pattern of congestion. Higher natural gas prices are expected to raise the incidence of congestion and therefore positively impact FTR payout. The risk-free interest rate at auction time is not likely to have a significant effect on payout itself; however, research, for example, Frankel (2014), has identified a negative relationship between the risk-free interest rate and commodity returns. Evidence that either of these variables is statistically significant implies that the forward price is informationally inefficient. Summary statistics regarding natural gas prices, expressed in Canadian currency, and interest rates are reported in Table 4.[17]

## 6. ECONOMETRIC APPROACH

The following panel regression equation is considered:

$$ln\left(payout_{p,t}\right)=\alpha_0+\alpha_1 ln\left(MCP_{p,t}\right)+\theta_1 ln\left(ng_t\right)+\theta_2 ln\left(r_t\right)+v_p+\varepsilon_{p,t} \quad (9)$$

where the dependent variable is the logarithm of the realized payout for path $p$ in validity period $t$, $MCP_{p,t}$ is the auction market clearing price of the FTR for path $p$ in validity period $t$, $ng_t$ is the natural gas price at the time of the auction, $r_t$ is the risk-free interest rate at the time of the auction, and $v_p$ is a path-specific effect. The set of paths and validity periods was described previously.

As discussed in section 4.1, equation (9) is estimated without the inclusion of the natural gas and interest rate variables to investigate the forward market unbiasedness hypothesis. Equations (5) and (6), respectively, are the strong and weak null hypotheses of forward market unbiasedness. They are repeated below and are tested against the general alternative.

$$H_0:\left(\alpha_0,\ \alpha_1\right)=\left(0,1\right) \quad (5)$$

$$H_0:\alpha_1=1 \quad (6)$$

As discussed in section 4.2, equation (9) is estimated with the inclusion of the natural gas and interest rate variables to investigate the informational efficiency hypothesis. Equation (9), with

17. The natural gas price is from the U.S. Energy Information Administration (series number N9190US3, “U.S. Natural Gas Wellhead Price”). The exchange rate used to convert the natural gas price from U.S. to Canadian currency is from the Bank of Canada (“United States dollar, noon spot rate, average,” reported in CANSIM Table 176-0064). The interest rate is also from the Bank of Canada (“Treasury bills: 1 month,” reported in CANSIM Table 176-0043).

**Table 5: Forward Unbiasedness Estimation Results**

| Model: Number of bidders | All auctions | One or two | Two | Three | Four or five | Four to seven |
|---|---|---|---|---|---|---|
| **Log (MCP)** | 0.632****<br>(0.176) | 0.381*<br>(0.198) | 0.563***<br>(0.191) | 0.770****<br>(0.156) | 0.715***<br>(0.242) | 0.969****<br>(0.211) |
| **Constant** | 3.081**<br>(1.429) | 5.153***<br>(1.592) | 3.717**<br>(1.565) | 1.972<br>(1.302) | 2.557<br>(1.981) | 0.577<br>(1.834) |
| **Chi-statistic (p-value)** | 12.949<br>(0.000) | 3.713<br>(0.054) | 8.675<br>(0.003) | 24.279<br>(0.000) | 8.724<br>(0.003) | 21.133<br>(0.000) |
| **N** | 143 | 70 | 60 | 33 | 32 | 40 |

Notes: Robust standard errors in parentheses, except for p-value associated with F-statistic; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$.

$(\theta_1, \theta_2) = (0,0)$, is the null hypothesis of informational efficiency and it is tested against the general alternative. In all cases, equation (9) is estimated with a random-effects estimator.

To investigate the impact of the number of bidders on the unbiasedness and informational efficiency of the auction, equation (9) is also estimated with several sub-sets of observations. In order that each set contain at least 30 observations and that the number of bidders in a sub-set be limited to adjacent integers (e.g., one and two but not one and three), the following sub-sets of number of bidders are considered: (i) one or two, (ii) two, (iii) three, (iv) four or five, and (v) four to seven.

## 7. ESTIMATION RESULTS

### 7.1 Forward Market Unbiasedness

The estimation results are reported in Table 5 and the hypothesis test results are reported in Table 7. For all statistical tests, a 95 percent level of confidence is used unless otherwise stated.

#### *7.1.1 All auctions*

Consider the results using all 143 auctions. The coefficient estimate associated with the MCP is 0.632 and is statistically greater than zero and less than unity. This indicates that a one percent increase in the MCP is associated with an average 0.6 percent increase in the payout. The constant is statistically greater than zero. The overall chi-square test result is statistically significant.

The weak version of the forward market unbiasedness hypothesis is rejected while the strong version is not rejected. The conflicting results indicate that a one percent increase in the MCP does not correspond to a one percent increase in the payout when tested by itself (rejection of the weak version), when the test is expanded to also consider whether the intercept is equal to 0, the combination is not rejected (the strong version). This suggests that there is mixed evidence of forward market unbiasedness when all auctions are considered.

#### *7.1.2 One or two bidders*

Of the 143 auctions, 70 of them had either one or two bidders. Considering only these 70 auctions, the coefficient estimate associated with the MCP is 0.381, which is statistically greater than zero (at a 90 percent level of confidence) and less than unity. This indicates that a one percent increase in the MCP is associated with an average 0.4 percent increase in the payout. It is notable that this estimate is well below the estimate of 0.632 when all auctions are considered. The constant is statistically greater than zero. The overall chi-square test result is statistically significant at a 94 percent level of confidence.

Considering auctions with one or two bidders, both the strong and weak versions of the forward market hypothesis are rejected. This suggests that when auctions have only one or two bidders, the forward market price is a biased (under) forecast of the spot price.

Of the 70 auctions with one or two bidders, 60 of them had two bidders. Considering only these 60 auctions, the coefficient estimate associated with the MCP is 0.563, which is statistically greater than zero and less than unity. This indicates that a one percent increase in the MCP is associated with an average 0.6 percent increase in the payout. It is notable that while this estimate is below the estimate of 0.632 when all auctions are considered, it is greater than the estimate of 0.381 when auctions with one or two bidders are included.

Considering auctions with two bidders, the strong version of the forward market hypothesis is not rejected (though it would be at a 94 percent level of confidence) while the weak version is rejected. The conflicting results indicate that a one percent increase in the MCP does not correspond to a one percent increase in the payout (rejection of the weak version), when the test is expanded to also consider whether the intercept is equal to 0, the combination is not rejected (the strong version).

#### *7.1.3 Three bidders or more than three bidders*

In 73 of the 143 auctions there were three or more bidders. As reported in Table 2, 33 of these had three bidders, 20 had four bidders, 12 had five bidders, six had six bidders, and two had seven bidders. As discussed in section 6, the groups of 33 auctions with three bidders, 32 auctions with four or five bidders, and 40 auctions with four or more bidders are investigated (the latter two overlap).

The estimation results, including their statistical significance, and related hypothesis test results are qualitatively similar across these groups of bidders. In particular, for each group the coefficient estimate associated with the MCP is not statistically different from unity but is greater than zero, the constant is not statistically different from zero, and the overall chi-square test result is statistically significant. With respect to the specific estimates, the results indicate that a one percent increase in the MCP is associated with an average 0.8 percent increase in the payout when there are three bidders, an average 0.7 percent increase in the payout when there are four or five bidders, and an average one percent increase in the payout when there are four or more bidders.

The similarity of results across the groups of bidders extends to the hypothesis results. In each case, the strong and weak versions of the forward market unbiasedness hypothesis fail to be rejected. This indicates that when there are three or more bidders, there is evidence that the forward market unbiasedness hypothesis holds.

Notable about these results is that, notwithstanding none of the estimates being statistically different from unity, there is a tendency for the estimates to be increasingly close to unity when there are more bidders. Indeed, this tendency is not limited to auctions with three bidders or more: it is a general pattern across all the groups of auctions considered.

### 7.2 Informational Efficiency

The estimation results are reported in Table 6 and the hypothesis test results are reported in Table 7.

**Table 6: Forward Market Efficiency Estimation Results**

| Model: Number of bidders | All auctions | One or two | Two | Three | Four or five | Four to seven |
|---|---|---|---|---|---|---|
| Log (MCP) | 0.614****<br>(0.153) | 0.388**<br>(0.177) | 0.502***<br>(0.174) | 0.608****<br>(0.158) | 0.757****<br>(0.213) | 0.900****<br>(0.144) |
| Log (Natural gas price) | 0.573<br>(1.455) | 0.286<br>(1.590) | 1.102<br>(1.339) | 2.382<br>(3.786) | 1.993<br>(2.511) | 2.220<br>(2.798) |
| Log (Risk-free interest rate) | –0.168<br>(0.285) | –0.241<br>(0.461) | –0.406<br>(0.435) | –0.344<br>(0.902) | –0.621<br>(0.495) | –0.439<br>(0.535) |
| Constant | 2.284<br>(3.156) | 4.774<br>(3.028) | 2.473<br>(2.855) | –1.012<br>(6.144) | –0.996<br>(5.369) | –2.791<br>(5.674) |
| Chi2-statistic (p-value) | 18.049<br>(0.000) | 4.888<br>(0.180) | 8.591<br>(0.035) | 30.559<br>(0.000) | 25.894<br>(0.000) | 77.602<br>(0.000) |
| N | 143 | 70 | 60 | 33 | 32 | 40 |

Notes: Additional results using all auction data: the Hausman test of random- and (unreported) fixed-effects yields a test-statistic value of 6.85 (p-value = 0.0768); the Breusch-Pagan LM test that the variance of the path-specific effects is zero yields a test-statistic value of 2.96 (p-value = 0.0427); Pesaran's test of cross-sectional independence yields a test-statistic value of 1.233 (p-value = 0.2177). Robust standard errors in parentheses (except for p-value associated with Chi2-test statistic); * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$.

**Table 7: Hypothesis Test Results**

| Model: Number of bidders | All auctions | One or two | Two | Three | Four or five | Four to seven |
|---|---|---|---|---|---|---|
| Strong unbiasedness | 4.65<br>(0.0977) | 10.49<br>(0.0053) | 5.64<br>(0.0595) | 2.32<br>(0.3134) | 2.11<br>(0.3481) | 0.44<br>(0.8017) |
| Weak unbiasedness | 4.38<br>(0.0363) | 9.83<br>(0.0017) | 5.23<br>(0.0222) | 2.16<br>(0.1418) | 1.39<br>(0.2181) | 0.02<br>(0,8838) |
| Efficiency | 0.38<br>(0.8288) | 0.34<br>(0.8446) | 0.96<br>(0.6185) | 2.29<br>(0.3179) | 2.60<br>(0.2728) | 0.69<br>(0.7099) |

Note: In each cell is the relevant F-statistic with the associated p-value below in parentheses.

In all the groups of auctions investigated, the natural gas price and interest rate at the time of the auction are each statistically insignificant. While the point estimates associated with the MCP for each group of auctions change by a very small amount with the inclusion of these variables, the general pattern of the coefficient increasing toward unity as the number of auctions grows is maintained.

The null hypothesis of informational efficiency is investigated through a joint test of the significance of the natural gas price and interest rate. For all the groups of auctions investigated, this is not rejected. This indicates that this information, which was available at the time of the auction, was accounted for in the auction result and supports a finding of informational efficiency.

### 7.3 Potential Simultaneity Bias

Using the number of FTR sold in a given auction as a potential instrument, it is possible to consider whether the number of bidders is endogenous by augmenting equation (9) with instruments in the form of dummy variables that control for the number of bidders (both the level and the interaction with MCP) and then calculating the C-statistic to test the exogeneity of these instruments.

The results indicate that the number of bidders can be treated as exogenous. This is consistent with the MCP and number of bidders being determined jointly in the auction market. The number of FTR sold for a path is a valid instrument because it may affect the MCP in that path's auction but is unlikely to impact realized wholesale market prices and FTR payouts. This is because realized wholesale market prices and FTR payouts are impacted by the physical availability of transfer capability rather than the number of FTR.

## 8. CONCLUSION

This paper examines the performance of FTR auctions in Ontario's restructured electricity market. It finds that over the period 2003 to 2011, FTR auction MCP were substantially lower than realized payouts. While it finds mixed evidence that MCP is an unbiased forecast of payout (congestion) when all auctions are considered, there is evidence that the MCP is an unbiased forecast of payout in auctions with at least three bidders and a biased forecast where there are fewer bidders. There is no evidence that information available at the time of the auction is not accounted for by the MCP.

There is little to support the proposition that the auction of FTR has made the Ontario market more efficient. A majority of electricity trades between Ontario and neighboring markets occur without a hedge that could be provided by an FTR and a substantial volume of FTR are procured and held by speculators not engaged in trade. Moreover, as Ontario's market has developed into one in which virtually all generation capacity therein is either under contract with or owned by government, forward-looking generation investors have no need to secure their investment with forward sales. Under these circumstances, it is unlikely that the auctioning of FTR contribute to the efficiency of the Ontario market.

Unless FTR auction prices begin to approximate realized congestion rent more closely, consumers would likely be better off if congestion rent is used to reduce transmission charges (or otherwise transferred to them) rather than be sold at auction. Implementation of internal locational pricing would not, by itself, change this result.

A variety of extensions on this work may be worth pursuing. For example, given evidence that greater competition in auctions yields more informationally efficient outcomes, the determinants of the number of bidders is worthy of consideration. The performance of the auction market for short-term FTR, which because of missing data presents significant technical challenges, also merits consideration. Finally, as discussed above, FTR are effectively financial derivatives. Research into why quasi-public independent electricity system operators such as the IESO should be mandated to provide FTR, instead of leaving the provision of these products to the financial services industry that provides derivative products in other industries, would also be worthwhile.

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## REFERENCES

Botterud, Audun, Tarjei Kristiansen, and Marija Llic (2009). "The relationship between spot and futures prices in the Nord Pool electricity market." *Energy Economics* 32 (5): 967–78. https://doi.org/10.1016/j.eneco.2009.11.009.

Frankel, Jeffrey (2014). "Effects of speculation and interest rates in a 'carry trade' model of commodity prices." *Journal of International Money and Finance* 42: 88–112. https://doi.org/10.1016/j.jimonfin.2013.08.006.

Hadsell, Lester and Hany Shawky (2009). "Efficiency and profit in the NYISO transmission congestion contract market." *Electricity Journal* 22 (9): 47–57. https://doi.org/10.1016/j.tej.2009.09.006.

Hodgson, Douglas, Oliver Linton, and Keith Vorkink (2004). "Testing forward exchange rate unbiasedness efficiently: A semiparametric approach." *Journal of Applied Economics* 7 (1): 325–53.

Hogan, William (1992). "Contract networks for electric power transmission." *Journal of Regulatory Economics* 4 (3): 211–42. https://doi.org/10.1007/BF00133621.

Hogan, William (2013). Financial transmission rights: Point-to point formulations. In Rosellón, Juan and Tarjei Kristiansen (eds.) (2013). *Financial transmission rights: Analysis, experiences and prospects*. Springer.

Holt, Charles A. (1980). "Competitive bidding for contracts under alternative auction procedures." *Journal of Political Economy* 88 (3): 433–45. https://doi.org/10.1086/260878.

Independent Electricity System Operator (IESO) (2013). *Transmission rights market review: Phase 1 analysis: Results and recommendations*. August, 9. Available online at: http://www.ieso.ca/-/media/files/ieso/document-library/engage/se110/se110-20130909-phase_1_analysis_results-revised.pdf?la=en

Independent Electricity System Operator (IESO) (2017). *Market Rules for the Ontario electricity market*. Available online at: http://www.ieso.ca/en/sector-participants/market-operations/market-rules-and-manuals-library

Independent Electricity System Operator (IESO) (various dates). *Monthly market report*. Available on a month-by-month basis online at: http://www.ieso.ca/sitecore/content/ieso/home/power-data/market-summaries-archive

Keane, Michael P. and David. E. Runkle (1990). "Testing the rationality of price forecasts: New evidence from panel data." *American Economic Review*, 80(4): 714–35.

Market Design Committee (1999). *The final report of the Market Design Committee*.

Market Surveillance Administrator (2015). *Q2/2015 Quarterly Report*. Available online at https://albertamsa.ca/uploads/pdf/Archive/000-2015/2015-09-02%20%20MSA%20Q2%20Report.pdf.

Market Surveillance Panel (2010). *Monitoring report on the IESO-administered electricity market for the period November 2009 to April 2010*. Available online at www.ontarioenergyboard.ca/oeb/_documents/msp/msp_report_20100830.pdf.

Ng, Serena and Pierre Perron (1995). "Unit root tests in ARMA models with data-dependent methods for the selection of the truncation lag." *Journal of the American Statistical Association* 90 (429): 268–81. https://doi.org/10.1080/01621459.1995.10476510.

Olmstead, Derek E. H. (2012). *Public policy and economic efficiency in Ontario's electricity market: 2002 to 2011*. Ph.D. thesis.

Ontario Ministry of Energy, Science, and Technology (1997). *Direction for change: Charting a course for competitive electricity and jobs in Ontario*.

Organisation for Economic Cooperation and Development (OECD) (2006). *Competition in bidding markets*. Available online at http://www.oecd.org/daf/competition/abuse/38773965.pdf.

Rivard, Brian and Adonis Yatchew (2016). "Integration of renewables into the Ontario electricity system." *The Energy Journal* 37 (SI2): 221–42. https://doi.org/10.5547/01956574.37.si2.briv.

Rosellón, Juan and Tarjei Kristiansen (eds.) (2013). *Financial transmission rights: Analysis, experiences and prospects*. Springer. https://doi.org/10.1007/978-1-4471-4787-9.

Schwert, G. William (1989). "Tests for unit roots: A Monte Carlo investigation." *Journal of Business and Economic Statistics* 7(2): 147–59. https://doi.org/10.1080/07350015.1989.10509723.

Siddiqui, Afzal, Emily Bartholomew, Chris Marney, and Shmuel Oren (2005). "Efficiency of the New York Independent System Operator market for transmission congestion contracts." *Managerial Finance* 31 (6): 1–45. https://doi.org/10.1108/03074350510769686.

Zivot, Eric and Donald Andrews (1992). "Further evidence on the great crash, the oil shock, and the unit root hypothesis." *Journal of Business and Economic Statistics* 10 (3): 251–70. https://doi.org/10.1080/07350015.1992.10509904.