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Measuring demand responses to wholesale electricity prices using market power indices☆

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ABSTRACT

We investigate wholesale demand response to hourly price movements in the Ontario wholesale electricity market using detailed generator and market level data. We calculate hourly market power measures such as the Lerner Index and the Residual Supplier Index, which are utilized in a Cournot competition model to structurally estimate price elasticity of demand during peak hours of days, seasons and years. We find that price elasticities are small and statistically significant, and they exhibit large variations over the times of days/seasons and show differences over the years. For instance, while the elasticity estimates fall into the range [−0.021, −0.133] in 2007, they are in the interval of [−0.013, −0.053] in 2008. We also extend the study period to include 2006 (during which extreme weather conditions occurred) and 2009 (when the economic crisis hit and natural gas prices plummeted) to measure the demand responses to irregular price movements and find that price elasticities during the economic crisis were higher than a year earlier. Comparing high demand winter hours to high demand summer hours indicates that consumers' price responsiveness is lower in summer than in winter during 2006–2009. Moreover, we employ these indices along with the estimated price elasticities to project the likely impact of interconnection capacity expansions on market prices. Our calibrations show that even a small amount of transmission investment (and hence trade activity) can result in substantial market price reductions. In addition, we discuss how our approach could be used to estimate price elasticities for other goods such as crude oil and gasoline.

1. Introduction

Electricity is an essential commodity and an input for production. While the process of reforming electricity markets continues, demand for electricity is growing at a fast pace and electricity prices are increasing at both wholesale and retail levels throughout the world. Electricity price affects the prices of many final goods, and the electricity industry is the largest single source of greenhouse gas emissions (EPA, 2014). It is associated with global warming and hence viewed as a negative externality in many jurisdictions.[1] To mitigate its side effects many Renewable Energy Laws in the world have been implemented by regulators and/or governments to encourage balanced electricity production portfolios and foster the share of green production technologies such as wind and solar. In addition, transmission investment and electricity market integration have gained momentum to overcome efficiency, security, reliability and sustainability issues, and reduce emissions. Given that electricity prices are increasing both at retail and wholesale levels, the recent demand management programs have targeted end users to be part of the restructuring process and to respond to prices by reducing demand, purchasing efficient electrical equipment, and changing consumption habits. The success of these demand response programs depends on the pricing policies that customers are subjected to.

The analyses of demand response to new pricing policies have gained considerable attention in the recent literature. It is imperative for market designers, system operators, power producers, regulators, and policy makers to predict how wholesale and retail customers would respond to market-based rates (e.g., wholesale market clearing prices) or regulated rates (e.g., time-of-use prices). For example, in the case of low price responsiveness or near zero price elasticity of demand market price can theoretically increase up to the price cap and cause market failures. This has been observed in several wholesale power markets in the world.[2] On the other hand, a high price responsiveness may render welfare improving market outcomes (such as low prices, saving energy resources and reducing costly power generations and

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[1] Global warming might be responsible for the current extreme weather changes causing unprecedented floods and droughts, and hence directly impacting production and services in several sectors. As the weather is an important factor of electricity demand, it can change electricity consumption behavior. In Ontario, coal plants have been phased out to reduce air emissions.

[2] Examples include the California, Texas, and Ontario markets.

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emissions). However, which price mechanisms may lead to more efficient results in a given market has not been clearly addressed mainly due to market design issues, and the difficulties associated with allocation of fixed costs of operations in the industry.

To create price responsiveness in the retail sector, regulatory agencies have implemented several pricing methods such as time-of-use prices, multi-tier prices, and wholesale market clearing prices. For instance in the US, only 1% of households are subjected to time-varying rates and 1% of this 1% are on dynamic pricing rates.[3] In Ontario, Canada time-of-use pricing was initially implemented for the retail market in mid-2005 and gradually extended with smart meter installations. Several recent studies analyze the impact of forms of static and/or dynamic time-varying pricing methods applied to residential and small commercial/industrial customers. In this literature, a number of studies have extended the work of Vickrey (1971) and Chao (1983) to incorporate the efficiency gain analysis and price responsiveness predictions for pilot projects run in certain cities/states/provinces.[4] Price elasticity estimates in this literature are distributed over a large interval and highly variable depending on the rate structures and locations.[5]

The price elasticity of electricity demand studies have mainly investigated price responsiveness of residential (and small industrial and business) customers who essentially face some fixed regulated rates.[6] In contrast, research incorporating wholesale customers subjected to real-time market prices is rare[7]. In this paper we focus on demand response of wholesale customers to hourly changing market prices. The wholesale customers/buyers are comprised of large industrial firms, regional electricity distribution companies, dispatchable loads and exporters who are the key players on the demand side and face highly volatile real-time market prices.

In this paper, we utilize an hourly Ontario wholesale electricity market data set of over 35,000 observations for each variable including firm/generator and market level outputs, costs and prices. An advantage of using Ontario market data is that we observe actual hourly outputs and available capacities of generators right after the market clears. Using this disaggregated data set, we initially assess the competitiveness of the Ontario market and calculate market power measures: the Residual Supply Index (RSI), and the Lerner index (LI) using hourly generator and market level data. We then model competition in the Ontario market as a capacity constrained Cournot model and solve it to derive the theoretical relationship between the RSI and LI. Using this relation and the computed hourly values of these indices we first estimate the wholesale price elasticity of demand over several time intervals in 2007–2008, which are the basis periods. We also extend the study period to include 1 year before and 1 year after (2006 and 2009).[8]

There are several distinctive features of this paper. First, we derive a price elasticity measure from a Cournot competition model. The structural modeling framework that we apply is appealing and easier to apply than other methods, which have to use more variables and data points to specify demand and/or supply curves. This could be a daunting task as some market and firm-level data are private and hard to obtain. An advantage of using our approach is that we do not need to model market demand explicitly. For example, we only assume that the market demand curve is downward sloping and differentiable. However, to our knowledge, measurements of price elasticities in the literature are almost exclusively based on reduced-form statistical models using some specific demand functions. Instead of dealing with demand specifications, we show how to use market power indices, which are easily computable due to readily available electricity data sets, to estimate the hourly price elasticity of demand in the short run. Second, in the estimation procedure we tackle the endogeneity issue between the market power indices by introducing an appropriate instrumental variable to obtain consistent and efficient elasticity estimates. Third, while other studies mainly focus on industry and/or residential layers of the sector and use weekly/monthly/yearly aggregated data, we employ detailed hourly generator and market level data to estimate wholesale demand response to hourly market price movements. Fourth, as an application of the model we examine the impact of several counterfactual supply scenarios regarding expansions in interconnection capacity facilitating trade activities. These scenarios are justifiable because transmission investments and hence the volume of trade between the neighboring jurisdictions/countries have been increasing since the opening of wholesale markets. Specifically, we will project the market prices in the case of an increase in import quantities from the adjacent markets in the transmission network. Finally, we discuss how our modeling framework could be used to estimate price elasticities for other goods such as crude oil, gasoline, computers, and cigarettes.

We find that there are a few players who are pivotal and are able to exercise market power in the Ontario market. In all of the generalized method of moments (GMM) and the ordinary least square (OLS) regressions we validate the theoretical negative relationship between the LI and RSI. Using the largest firm's RSI and the various LI measures we estimate price elasticities and find that the wholesale demand is price responsive, but only to a small extent – the price elasticities mainly fall in the range [−0.013, −0.133], and they change over peak and off-peak hours of seasons/years. While we use a structural approach in estimating elasticities these findings are consistent with the broader literature. To check the robustness of our elasticity estimates, we also use the fuel prices as a proxy for the marginal costs in computing the hourly LI. We find that the elasticity figures are similar both qualitatively and quantitatively regardless of whether we employ actual fuel prices or actual dollar amounts spent for each fuel type in the LI calculations.

The organization of the paper is as follows. Section 2 examines the Ontario market structure along with the specifics of the data sets. Section 3 defines the competition model employed in the paper. In Sections 4 and 5 we compute market power indices to determine competitiveness of the market and use these indices to estimate the hourly price elasticity of wholesale electricity demand in several periods of 2007 and 2008. Section 6 extends the study period to include years 2006 and 2009 to examine the impact of important events, and offers a robustness check for the estimated elasticities using an alternative marginal cost formulation. Section 7 proposes an application of the modeling framework to project likely impact of certain supply scenarios. Section 8 relates our results to the broader literature and assesses the extent to

[3] See Faruqui et al. (2014). Charging wholesale prices to retail customers is an example of dynamic pricing.

[4] Examples include Wolak (2011), and Faruqui et al. (2014), among others. See also Ryan et al. (1996) who examine residential energy (oil, gas, electricity, and wood) demand in Ontario using annual data for the period 1962–1989.

[5] For old studies, see Taylor (1975) who provides a detailed summary of econometric research on demand for electricity and mainly reviews residential demand models. In a recent study, Reiss and White (2005) estimate a household electricity demand model for assessing the effects of rate structure change in California. They find that a small fraction of households respond to price changes, and the price elasticities range from 0 to −2. Related to the price response of residential demand, Bushnell and Mansur (2005) estimate the impact of lagged residential prices on consumption and find that elasticity of demand equals −0.1 in San Diego, California.

[6] Taylor (1975) criticizes residential demand models and explains the difficulties associated with demand function specifications due to the fixed charges and price schedules stemming from different consumption blocks. He points out that these pricing features create non-analytical demand functions which render the validity of econometric estimates of price elasticity of demand questionable. See also Heshmati (2014) for a recent survey of electricity demand models using reduced-form formulations.

[7] Total system load/demand analysis was first carried out by Cargill and Meyer (1971) who employed a linear model, in which demand was represented as a linear function of average prices for gas and electricity, real per capita income, time and employment in manufacturing sector. They used monthly observations of 48 data points in the late 1960s, and found that price elasticity was negative and statistically different from zero.

[8] During 2006 natural gas prices started to increase before they hit record levels in 2007 and 2008. Year 2009 corresponds to the economic crisis period (in Canada and elsewhere) during which the North American natural gas spot prices plummeted and demand for electricity went down.