Power Trade, Welfare and Air Quality

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Electricity Industry

Features/novalties

-- non-storable;

-- continuous matching of demand and supply;

-- moves at the speed of light;

-- negative prices are common;

-- trade is continuous and simultaneous.

- A key contributor to GDP
- Associated with a climate change, health issues

  -- Power generation sector is the most polluting among all industries.

  -- Key pollutions are GHG, mainly CO2, and SO2 and NOx.

Wholesale Electricity Trade

- Cross-border wholesale electricity trade has been growing in Europe and North America.
- Canada is net exporter to the US.
- In 2009 Canada exported 51,108 GWh, and imported 17,490 GWh electricity from the US.

- Examine Ontario's trade with regulated (Manitoba and Quebec) and liberalized (New York, Michigan, Minnesota) markets.
- Interconnection trade capacity is over 4000 MW (1/6 of the production capacity, 2/9 of average demand).
- Imports 3.8%, 4.3%, and 6.5% of market demand.

Air Pollution

- Key pollutions are GHG, mainly CO_2, and SO_2 and NOx (depletion of ozone layer, and causing acid rain and smog)
- Environmental protocols (Kyoto, Copenhagen) and Renewable Energy Laws enacted to abate air pollution stemming from power generation. Hence green technologies (wind, PV) spurred.

Motivation

- Can we model competition in wholesale electricity markets?

- Given those laws and protocols, can electricity trade be an instrument or be a market mechanism to alleviate the air emissions?

  Evidence: New York market with dirty production technologies could import cheap and clean hydroelectric energy from the Quebec market and reduce its emissions.

Literature

- A number of papers examined various issues

  Green and Newbery (1992), Wolfram (1999), Borenstein et al (2000), Borenstein et al. (2002), Joskow and Kahn (2002), Wolak (2007), Hortacsu and Puller (2008), Mansur (2008), Genc (2009), Genc and Reynolds (2011), Fowlie et al (2012).

- Market power analysis, optimal bidding behavior, transmission investments, forward contracting, auction institutions, impact of market structure on the welfare, and environmental issues.

- Electricity trade analysis and impact of trade on market outcomes, welfare and environment have not been addressed.

What We Do

- Examine power trade between the Ontario wholesale electricity market and other national and international jurisdictions (New York, Michigan, Minnesota, Manitoba and Quebec).

- Study the Ontario market because

  i) unique features relative to the other electricity markets

  --- very volatile prices (the most volatile relative to the other deregulated markets in the neighborhood)

  --- relies on trade activities to clear its real-time market

  ii) detailed firm and market level data that are suitable to study environmental and welfare issues.

  iii) interconnected with large regulated and deregulated markets by the transmission grid over which the electricity trade occurs via wheeling-through transactions.

What We Do

- Model the competition in (hourly) ON wholesale electricity market,

  ---construct MC curves

  ---run the model and predict the market prices, production levels.

  ---calculate mark-ups

  ---compute the social cost of oligopoly.

- Address impact of wholesale electricity trade on the air quality and social welfare in a dynamic game-theoretic analysis.

  --how market outcomes change with respect to certain import and export scenarios?

  --what is the quantity of emission gasses released by each firm/production technology/generator?

  --how much CO_2, NO_x,SO_2 avoided if trade occurs?

  --how trade affects consumers and producers surplus?

What is New?

- New research question

--first paper addressing impact of trade on market outcomes and air emissions.

--social welfare implications of electricity trade

--air quality implications of trade

--negative wholesale prices and their impact

- New methodology

--hourly market model calibrations

--hourly cost function estimations

--comparing outcomes with IESO, and actual

Contributions

1. **Modeling**: Forecast the market prices with high accuracy (better than the IESO)

   For instance, in March 2008 hourly mean absolute error between our price estimations and the realizations is $2.5. It is $15 between the auctioneer's (ISO's) price estimations and the realizations.

   The price predictions are very close to the market transaction prices. In other months we observe similar patterns; our price predictions beat the IESO's predictions and our prices are near the realizations.

2. **Policy Implications**: Investment in transmission lines can cause welfare and air quality improvements.

Contributions

- There is no trade theory for electricity explaining the directions of imports/exports

- Electricity trade can impact generation behavior of power producers, and the mixture of power portfolios that firms hold and invest in, and the way they produce.

- Trade can cause substitution of fuel resources across markets.

Some Highlights

- Model generates equilibrium prices and outputs with 94.4% and 96% accuracy, resp.
- When hourly imports double from current levels, CO_2 emissions would decrease around 12.6%, and prices would reduce 5.4%.
- In autarky, CO_2, SO_2, NO_x emissions would increase 12%, 22%, 16%, resp., prices would go up 5.8%, and volatility would rise 12%.
- When market prices are negative welfare loss is 0.016% of the total loss.

- Average emission savings are 0.62 lbs of NO_x, 1.99 lbs of SO_2, and 0.3 tons of CO_2 per MWh import increase in Ontario in the year.

  (Kaffine et al. (2013) find emission savings from wind power in ERCOT are 1.3 lbs for SO_2, 0.79 lbs for NO_x, and 0.52 tons for CO_2 per MWh wind generation.)

- 1 MWh import reduction will result in 0.73 lbs of NO_x, 2.11 lbs of SO_2, and 0.29 tons of CO_2 emissions increases.

Data

- Detailed plant level and market level data from the IESO.

- The data set includes hourly export/import quantities, production and capacity of each generator in the market, hourly market clearing prices and quantity demanded, as well as technical features of generators and financial data.

Data

- In the Ontario market there are over 500 generators/ boilers of which we have their efficiency rates (energy content and heat rate) and capacities.
- The financial data provided by Statistics Canada includes information such as how much was spent on fuel (coal, nuclear, gas, oil, biomass, etc) by the firms.
- Have one-hour, two-hour and three-hour ahead pre-dispatch prices and quantities which are the market price and quantity demanded estimations done by the IESO.
- The data obtained from IESO, Statistics Canada and Environment Canada converted into a workable database.

Model

- Modeling the behavior of electricity producers

  firm strategies involve production decisions (a Cournot model);

  {firms choose price-quantity pairs as decision variables (Supply function equilibrium model).}

- Examine a quantity choice model in the market.
- Capacity Constrained Asymmetric Dominant Firms & Competitive Fringe with Multiple Technologies.

Ontario wholesale electricity market

- Study the Ontario wholesale electricity market between April 1, 2007 and March 31, 2008.

- The IESO makes hourly price and demand quantity predictions one-hour, two-hour and three-hour before the auctions for the following 24 hours.

Firms/Players

- There are about 563 generators in the Ontario market. Map generators to ownership.
- Assume dominant firms and competitive fringe competition model
- The dominant firms are Ontario power generation (OPG) Inc, Bruce Nuclear Inc, and Brookfield Renewable Energy.

Constructing Marginal Production Costs

Calculating marginal fuel cost of a generator

- Know the type of the fuel each generator consumes,
  each generator's heat rate,
  energy content of each fuel type, and
  the dollar amount spend on each fuel type.

Then calculate the marginal fuel cost of a generator as follows:

- MC_fuel_gen=Heat rate (kj/kwh)*$(dollar spent)/ [Fuel consumed (t)*Energy content (kj/kg)]=$/MWh

Externality Pricing: Marginal emission cost of a generator

- Emission permits are traded for NOx and SO2 gases in North America. Externality costs:

SO2 emission cost for a generator =HR_genset* SO2 rate of gen*price of SO2 emission permit

NOx emission cost for a generator =HR_genset* NOx rate of gen*price of NOx emission permit.

Total marginal cost of production for a generator

Total marginal cost for a generator =

MC_fuel_gen + SO2 emission cost of generator + NOx emission cost of generator.

The variables determining MC curve

VARIABLES

- Heat rate (HR)
- Energy content of a fuel
- $ spent on fuel
- Quantity consumption of a fuel
- SO_2 emission rate of a genset
- NO_x emission rate of a genset
- SO_2 permit price
- NO_x permit price
- Availability&Capacity of each genset

(The brace groups the first eight variables, from Heat rate through NO_x permit price.) → P (y axis)

Availability&Capacity of each genset → Q (x-axis)

Figure 1: System marginal cost curve with and without emission costs.

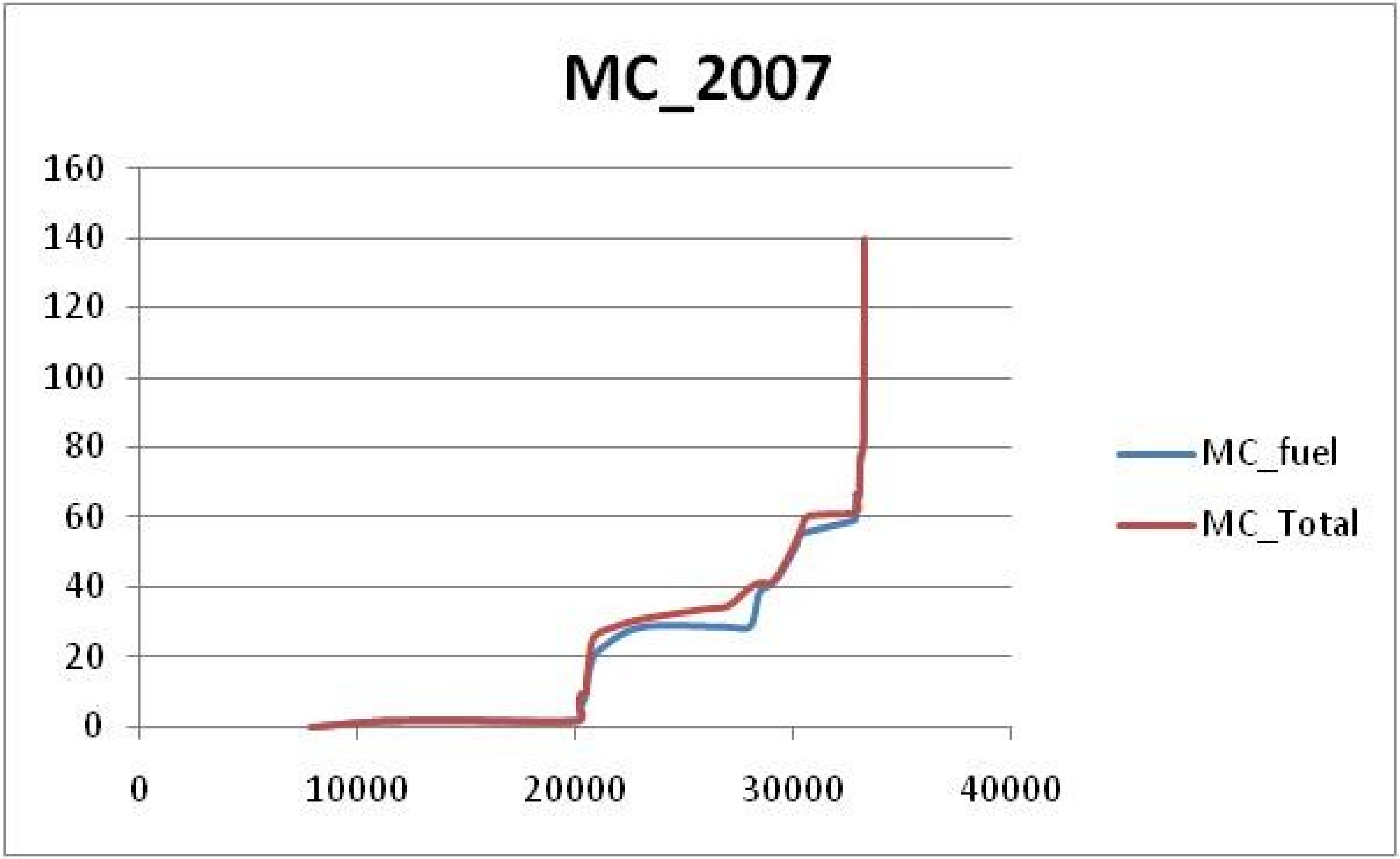
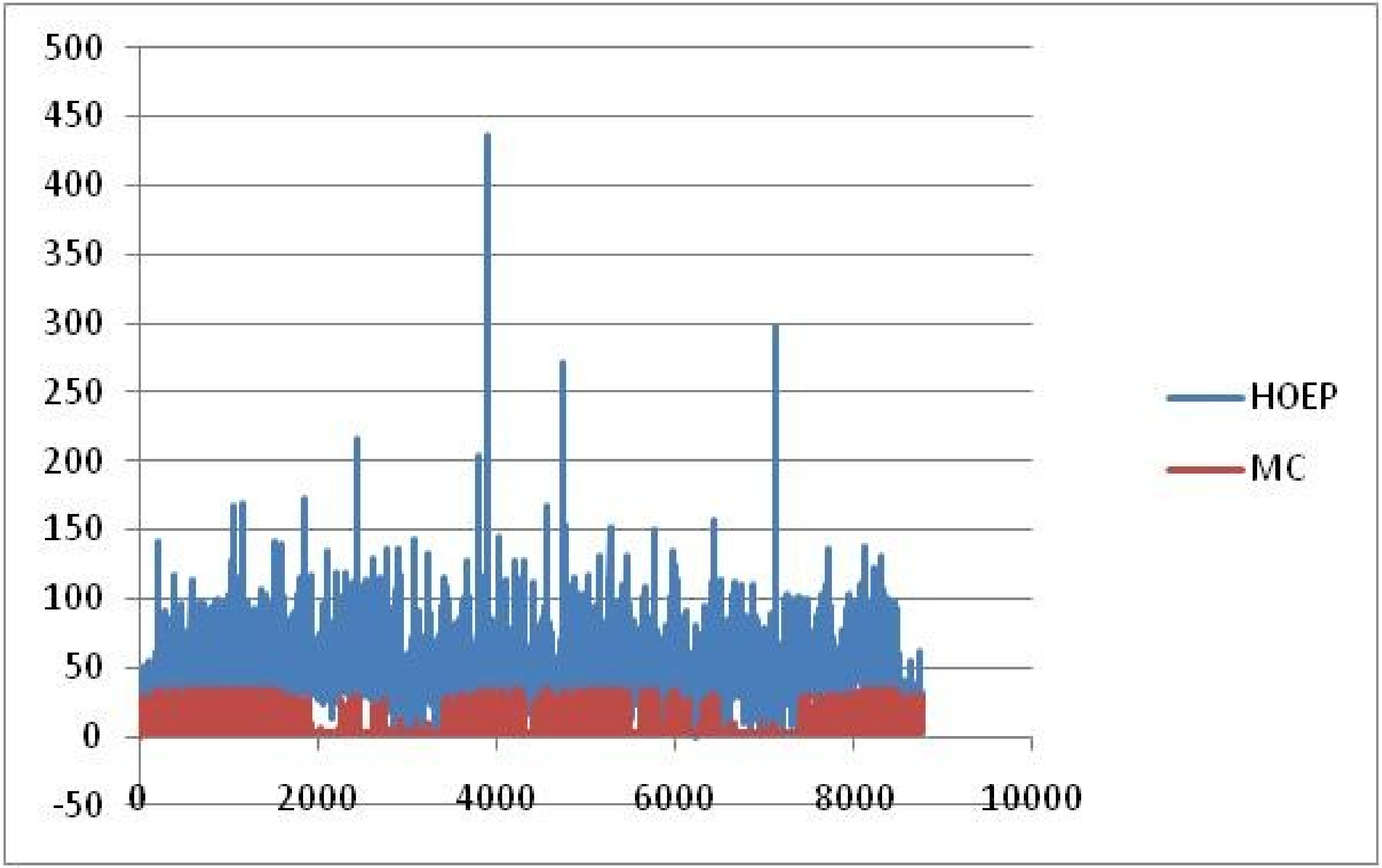


Figure 2: Time series plots of market prices and system marginal costs in year 2007. X =hours, Y= $/MWh.



Producers

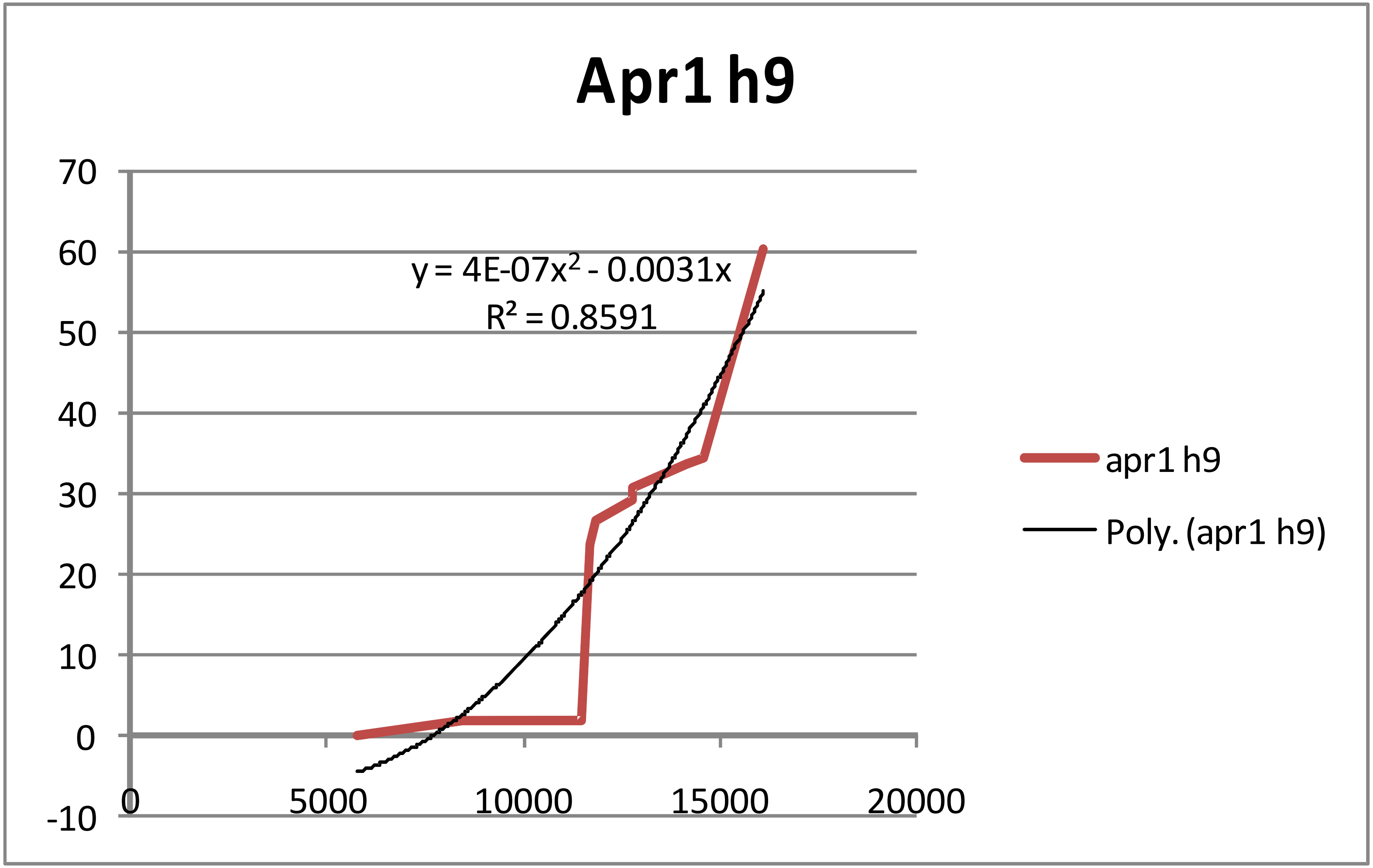
OPG (Ontario power generation): It has over 60 plants and they are formed by hydro, nuclear, coal, and natural-gas fired generators.

- Given the type of technology, available capacities and the marginal costs for each generator we obtain marginal cost function for OPG.
- For a given price level we horizontally add available capacities for each type of generator to obtain marginal cost function for OPG.
- The total available capacity of OPG generators changes every hour; the minimum available total capacity is 12900 MW, the maximum is almost 19900 MW, and the average is near 16900 MW per hour in year 2007.

OPG

- For each hour we can have a different marginal cost function since available capacities of generators change almost for each hour.
- After obtaining a marginal cost function we fit into a continuous function selected by highest R-square.
- For example, on April 1, 2007, hour 9, we obtain a quadratic marginal cost function in which the marginal cost at zero output is zero because OPG has hydro generators which operates at zero marginal cost (of fuel).

MC of OPG

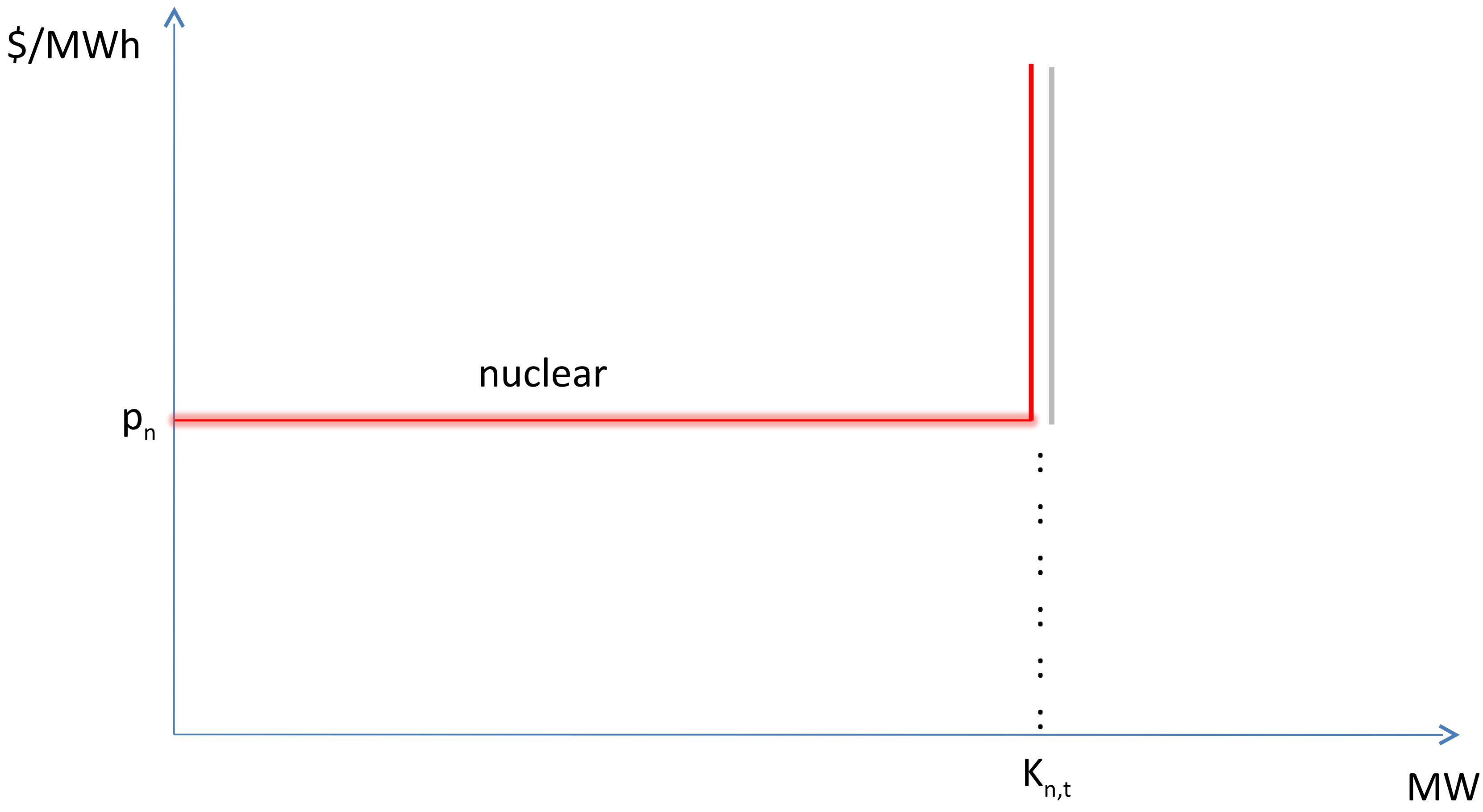


Apr1 h9
70
60
50
40
30
20
10
0
-10
0
5000
10000
15000
20000
y = 4E-07x2 - 0.0031x
R2 = 0.8591
apr1 h9
Poly. (apr1 h9)

BRUCE POWER

- Bruce nuclear has six nuclear generators with the identical heat rates; hence its marginal cost is constant.
- However, the marginal costs change over years as fuel costs, energy contents, and the amount of fuel (uranium) used differ.
- Total production capacity from those six nuclear stations changes every hour, and in 2007, its average total capacity is around 4200 MW.

Bruce MC Curve



BROOKFIELD RENEWABLE ENERGY

- It has hydro, wind and natural gas–fired generators.

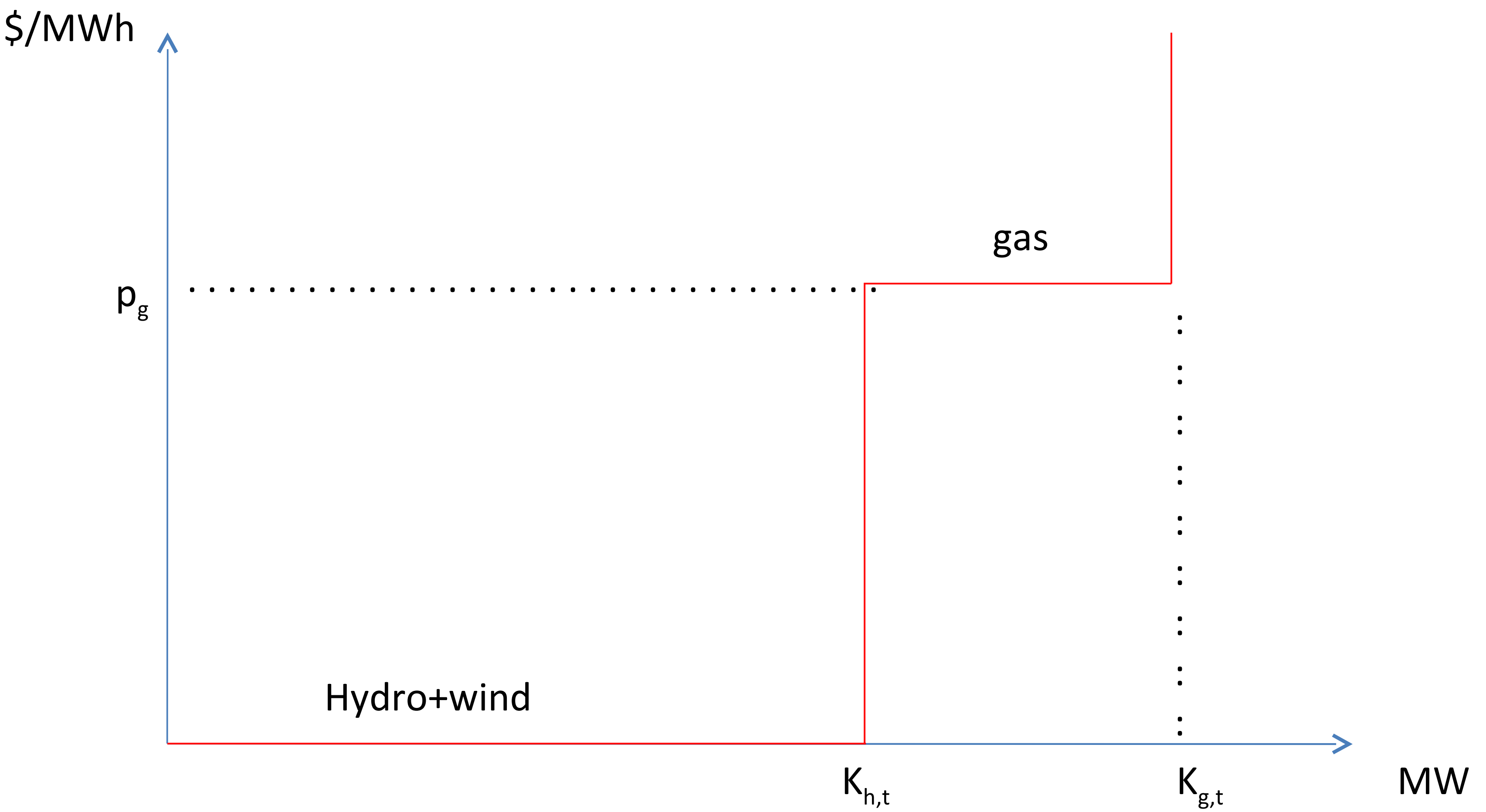
- Since marginal costs of hydro and wind units are zero, Brookfield has a two-step marginal cost function.

- Its marginal cost is zero up to the total hydro and wind capacities. Since it has one natural gas-fired generator, its marginal cost is constant

- Since the total marginal cost function has two steps, we do not smooth the step function; just treat zero marginal costs up to a time varying capacity and a positive marginal cost due to the natural gas unit. It has only one natural gas plant.

- In year 2007, even though its total available capacity varies from hour to hour, its total production capacity is on average around 1000MW.

Brookfield MC Curve



FRINGE SUPPLIERS

- Fringe producers are many and operate hydro, wind, biomass, and natural-gas fired technologies.
- Gas fired generators with different heat rates, emission rates and capacities.
- The available capacities of gas turbines vary in between 0 and 580 MW across generators.
- In 2007, the hourly average total available capacity

  gas generators:2170 MW, biomass:500 MW,

  hydro + wind: 400 MW
- Almost 15% of market demand is covered.

FRINGE SUPPLIERS

- Draw marginal cost curve as a function of available capacity in April 1 hour 1.

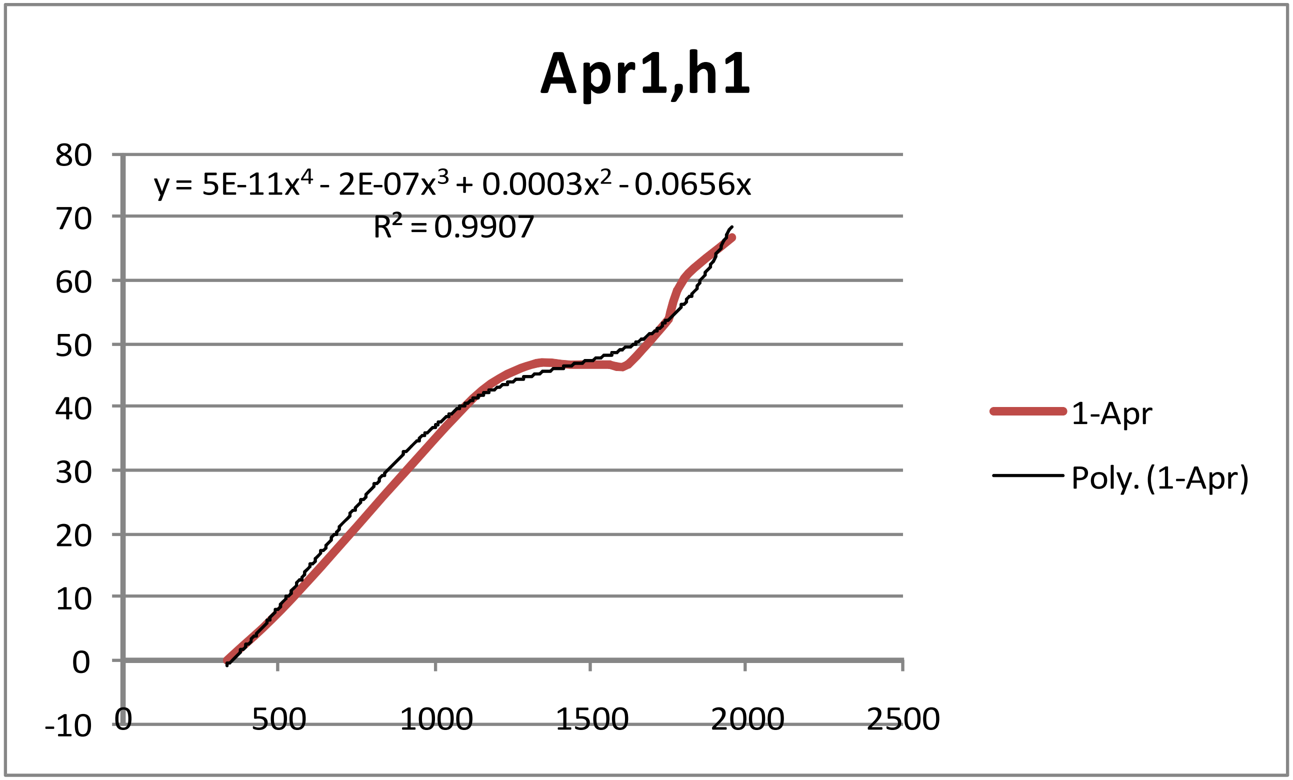
- The best fitting smooth function is the fourth degree polynomial for the marginal cost curve.

- Take the inverse of the marginal cost curve and obtain the inverse marginal cost function.

- Draw the inverse marginal cost function S(p) in the following figure with linear and fourth degree approximations. In terms of goodness of fit, there is little difference between a linear function and the fourth degree polynomial function.

- Observe similar patterns in other months and hours. Also, for the sake of tractability and avoiding the multiple equilibrium issue with the forth degree polynomial, assume linear inverse supply curve for each hour for the fringe suppliers.

Figure: Inverse Fringe supply curve and the approximation



Demand

- We employ a linear demand function with time varying intercept and slope terms.

- Use hourly clearing price and the quantity demanded for the years 2007-2008. Use the pre-dispatch prices for the same period.
- The IESO makes predictions of market prices and demand quantities for the future 24 hours.
- The IESO predictions usually deviated significantly from the realized price and quantity pairs.
- The IESO keeps track of those estimated prices starting April 2007.

- Using the realized prices and quantities demanded and a constant elasticity, we generate hourly demand curves.

Demand

- Estimating demand curve passing through the observed market price and market demand quantity.
- In calibrations we used several values for demand elasticity. The estimate for demand elasticity is in the range of 0.2 to 0.6.

- Lit. suggests [0.2, 0.8]. Elkhafif (1992) estimate it [0.4, 0.6], Borenstein and Bushnell (1999) use 0.1, 0.4,1.0.
- In a richer model, one could allow time varying elasticity.

Model

- All players are capacity constrained, which varies every hour
- Three strategic dominants firms with many nonstrategic fringe suppliers
- Q(p) is the market demand (Ontario demand plus exports).
- Each strategic firm, OPG, Bruce and Brookfield, solves its profit maximization problem.
- Price taker fringe firms

Model

- Demand:

[illegible]

- Residual demand

[illegible]

- Max Profit

[illegible]

s.t. [illegible]

[illegible]

Timing

- For auction at time =t (hour)

At t-1

- Update capacities for each firm, and market imports
- Construct cost curves for each dominant producer
- Construct supply curve for fringe suppliers
- Approximate the cost functions
- Estimate the demand curve
- Solve the model (Argonne National,NEOS-PATH solver)
- Record p, q_i (market price and quantity for each firm)
- Repeat for each t=1,…,8784

1. Assessing Model Performance

Price Estimations

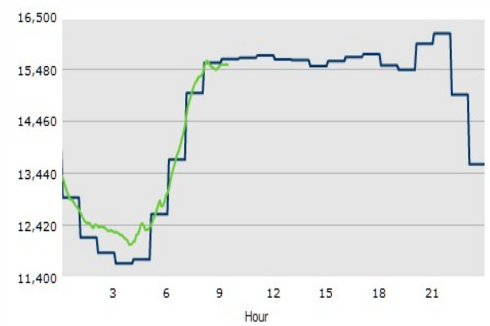
- To be able to address the policy issues (e.g. investments or emission targets), one needs to make sure that the model predictions are close to the market realizations.

- The market maker, the IESO, predicts the market prices to give directions to the market participants. We run our model and compare the model prices to the IESO predictions.

15,560 MW
at 9:00 a.m. EDT
May 15, 2013

Projected Demand at 10:00 a.m. EDT	15,693 MW
Today's Projected Peak (at 10:00 p.m. EDT)	16,200 MW
Summer Record Peak (Aug 1, 2006)	27,005 MW

Select: Yesterday Today Tomorrow

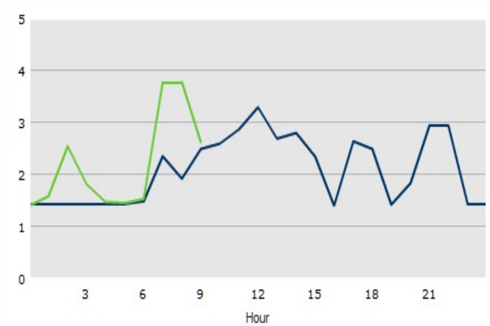


WHOLESALE PRICES

2.63¢/kWh
at 9:00 a.m. EDT
May 15, 2013

Average Weighted Price for May	2.75¢/kWh
Average Weighted Price since Jan 1, 2013	2.96¢/kWh

Select: Yesterday Today Tomorrow



Note: Pre-dispatch price shows projected prices based on offers currently in the market. This figure can fluctuate as new offers are submitted and demand changes.

Understanding Market Information
Here's a primer on key market information and how to use it to manage your energy use.

Regulated Prices
Homeowners and other designated consumers pay regulated prices for electricity.

Electricity Week
Read demand and price information for the past week.

Monthly Market Update
Read demand and price highlights for the previous month.

Power Outlook
Here is the assessment of available supply and demand requirements for the current quarter.

Monthly Average Prices
Compare wholesale prices since May 1, 2002

FOR MORE INFORMATION

More detailed market information is available on these pages on the Inside the Market section:

- Today's Market
- Market Data
- Market Summaries

Table 1: Mean absolute error (MAE); IESO predictions versus model predictions

Table 1: Mean absolute error (MAE); IESO predictions versus the model predictions

Time	**MAE (between IESO prices and transaction prices)**	**MAE (between model prices and transaction prices)**
March 2008 (hourly prices)	15	2.49
August 2007 (hourly prices)	10.22	4.07
Averaged over all hours	11.61	3.29

Figure: The comparison of MAE for our model price predictions and IESO predictions

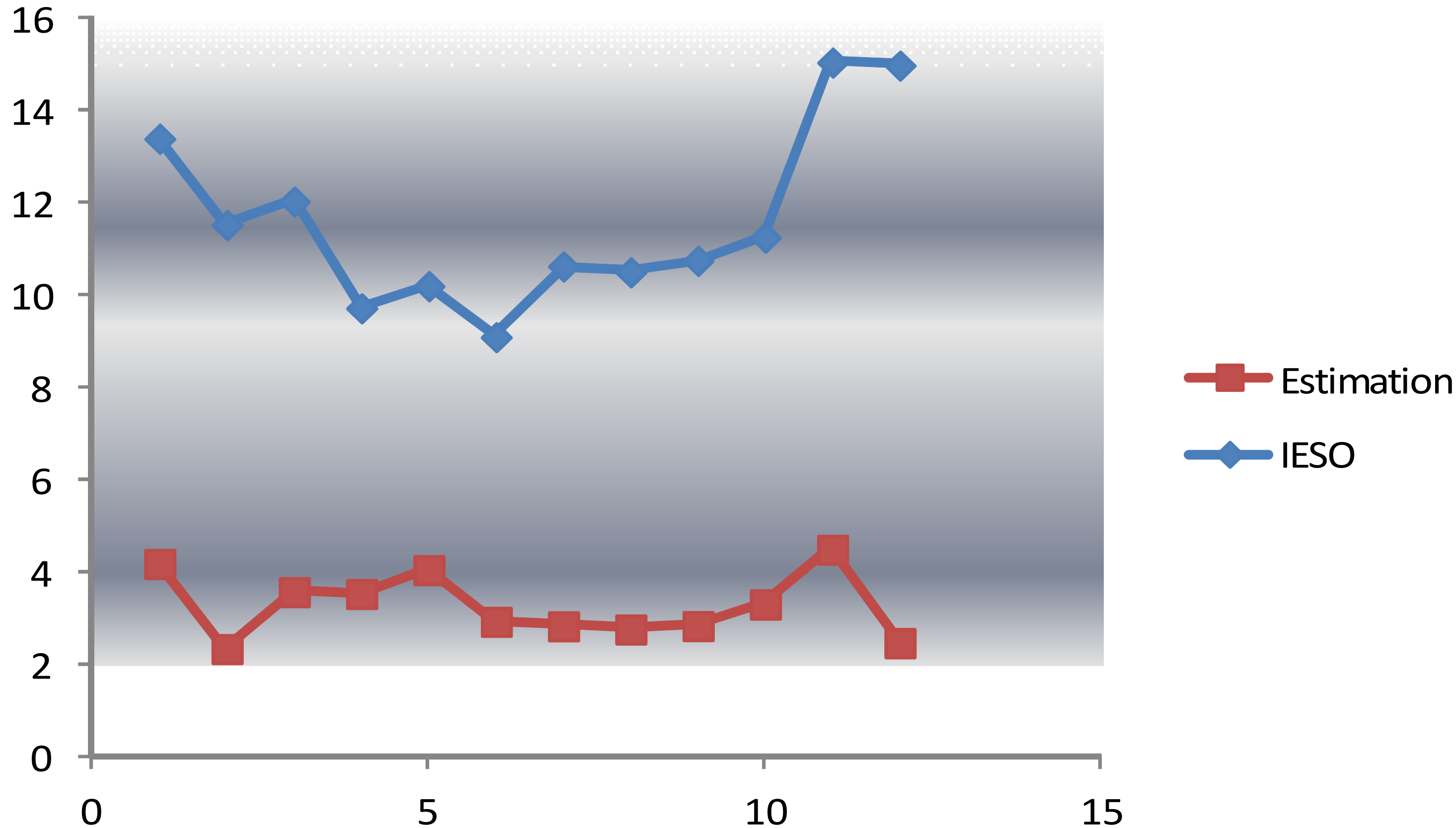
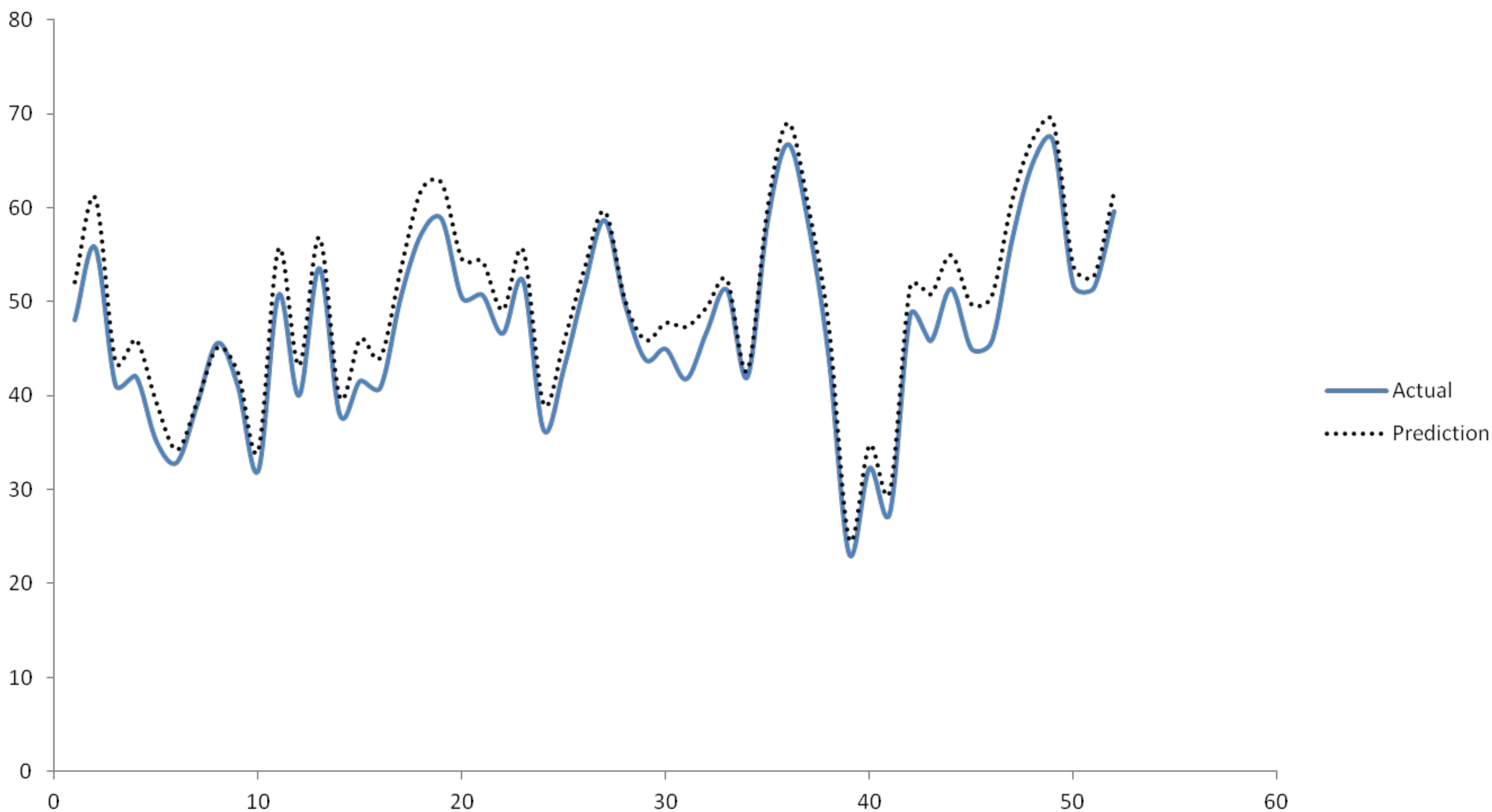


Table: summary statistics of hourly prices- Actual realizations, our model predictions, and IESO predictions between April 1, 2007 - March 31, 2008.

	Actual	**Model Prediction**	**IESO Prediction**
Average price	47.16	49.95	55.38
Stdev	25.21	26.37	25.59
Min price	-2.72	-6.95	2.9
Max price	563.62	572.58	193.87
Kurtosis	29.18	26.06	0.48
Skewness	2.49	2.37	0.68

Figure 4: Weekly prices in $/MWh-actual versus predictions; x-axis: weeks; y-axis: prices.



Price Estimations

- Our average hourly price for the year is $49.95 and the actual average price is $47.16.
- The model produces the hourly equilibrium prices with 94.4% accuracy.
- 1456 hours out of 8784 hours (17%) our hourly predicted market prices were below the actual market prices, and
- Remaining times (83%) our prices were above the market realizations.

Quantity Estimations

- In the year the average hourly demand estimations by the IESO and our model are 19,466 MWh, 18210 MWh, resp. The actual mean load quantity is 18,966 MWh.
- Our predicted average equilibrium load in the year is 4% below the realization.
- 1451 hours out of 8784 hours (16.5%) our predicted quantities are 2% above the actual demand quantities and in the remaining times (83.5% of time) our load estimations are 5% below the market realizations.
- The IESO over-predicts the market demand quantities 92.5% of the time (3% above the realized load).

Welfare Analysis

- Although trade is an important component of the wholesale electricity operations, social welfare implications of electricity trade have not been addressed.
- Also, a concern of market observers in power markets is the existence of negative wholesale prices and their impact on the welfare.

- Will measure the welfare gain/loss when the market prices happen to be negative.

Welfare Gain from Imports

- Compute and compare the welfare loss (dead weight loss, DWL) wrt change in import quantities.

- For a given hour run competition model at the actual import levels and obtain the equilibrium outcomes and compute the hourly DWL.

  (I=I, actual import levels).

- To measure welfare change wrt to change in import levels we examine market outcomes in two feasible scenarios/policies:

  -- in the absence of imports (I=0) (inv in renewable)

  -- in the presence of double the imports (I=2I) (transm.)

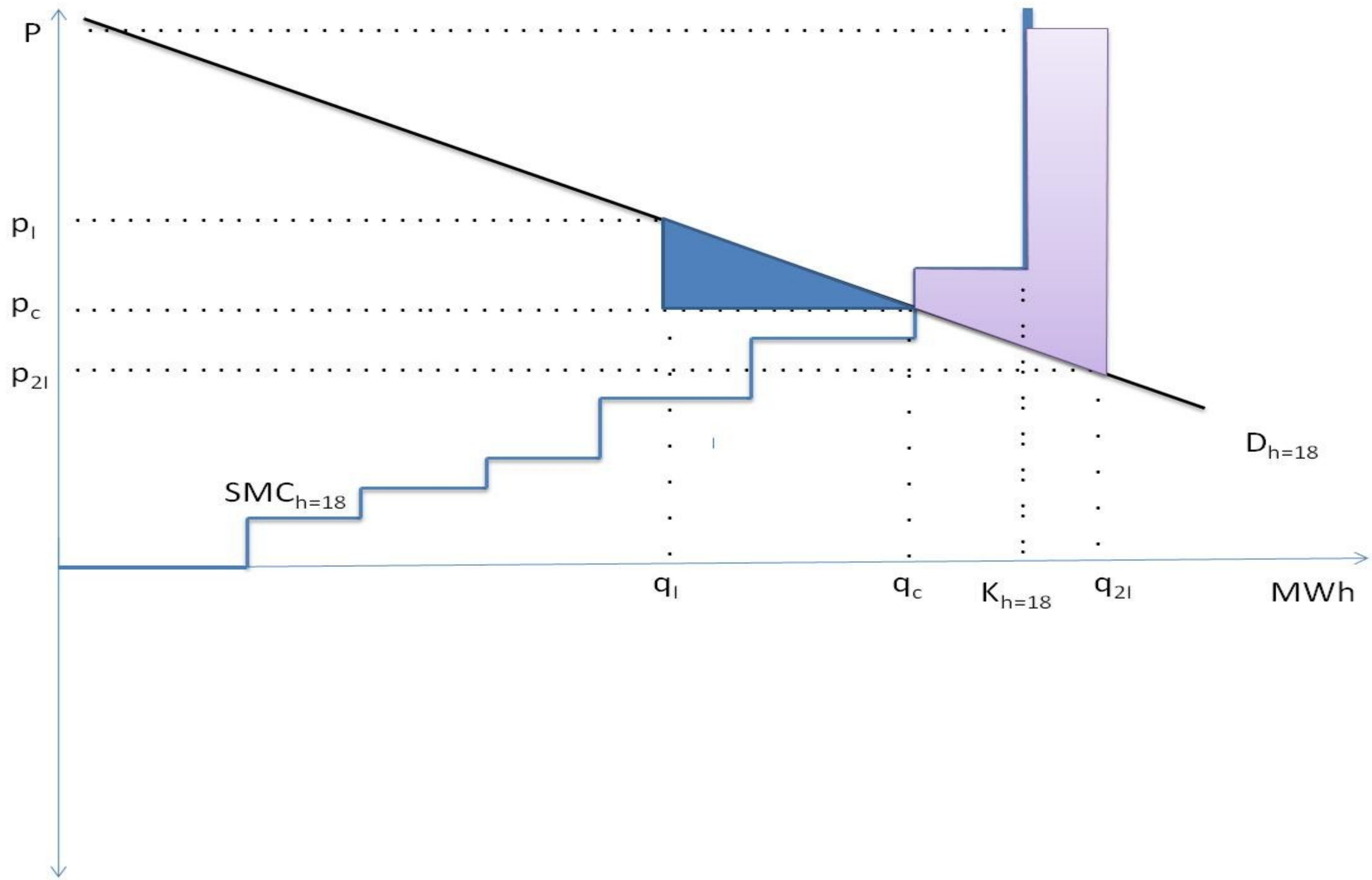
Table 3: Welfare loss, average prices and demand quantities with respect to change in imports.

Month / Import level	I=0	I=I	I=2I
4. 2007	41,190,907	34,886,200	29,340,601
5. 2007	33,446,595	21,9444,250	15,937,581
6. 2007	41,238,427	30,384,794	22,124,856
7. 2007	43,544,893	33,704,343	25,901,664
8. 2007	58,898,609	42,999,625	29,935,979
9. 2007	37,994,417	21,745,963	12,812,450
10. 2007	38,772,448	24,495,167	15,359,506
11. 2007	32,220,239	17,004,178	8,772,313
12. 2007	53,928,739	32,975,145	17,254,768
1. 2008	35,334,372	19,176,444	10,302,456
2.2008	53,475,813	34,918,621	21,992,323
3. 2008	53,818,528	27,913,605	13,815,287
Total DWL ($)	523,883,988	342,148,334	223,549,784
Change in Welfare ($)	-	181,735,654	118,598,550
Price ($)			
Average price	52.84	49.95	47.24
St. dev.	29.5	26.37	24.69
Skewness	4.58	2.37	2.48
Kurtosis	93.9	26.1	28.5
Demand quantity (MWh)			
Average demand	17559	18210	18837
St. dev	2302	2461	2696

2. Welfare Gain from Imports

- The relationship between imports and welfare loss over the months is monotonic.
- However, this relation does not hold for all hours. For instance, h=18 of March 7, 2008, DWL increases as the imports double.
- On the same day at hours 17 and 19, welfare loss always decreases in imports. The DWL is $13,078 at hour 18, however when the imports would double the DWL would skyrocket to $170,260.

Figure 5: Welfare loss at hour 18 of March 7, 2008 when production is above the available capacity.



Welfare Loss When Market Prices are Negative

- The spot market prices are negative during certain trading hours of the study period.
- Negative prices are common and indicate not only that the wholesale electricity is free but also that buyers (e.g., distribution companies) get paid to consume electricity.
- Sources: "excess production" injection to the transmission lines (to relieve the stress, otherwise system-wide problems such as black-outs).
- Producers do not make any payments to the buyers but the system/market operator, who is responsible from electricity network security and reliability, makes the payments.

Table 4: Negative prices, market outcomes, and the welfare loss.

Time	I=I				
	P($/MWh)	Q (MWh)	I (MWh)	E (MWh)	DWL($)
9.18.07, h=1	-0.4	14,130	1,107	815	8,219
2.18.08, h=2	-1.91	15,553	927	973	12,572
2.18.08, h=3	-2.72	15,454	975	1047	13,363
2.18.08, h=4	-1.39	15,530	954	990	11,060
2.18.08, h=5	-0.65	15,628	802	1150	9,096

Welfare Loss When Market Prices are Negative

- The total DWL in the year is $342,148,334 (in the Table 3), 4.2% of revenue.
- The total DWL during negative prices is $54,310.
- Therefore, the DWL during negative prices is just 0.016% of the total welfare loss.

3. Air Emission Offset by Imports

- Whether imports cause any reductions in the emissions will be addressed.
- The answer for whether imports abate emissions in a local market is not obvious

--- A key issue is what generators imports would displace; dirtier or cleaner technologies.

-- If the imports are displacing dirtier local generators, then they can cause → emission reductions.

-- If the imports displace expensive and relatively cleaner generators (like NG), then the low cost and dirtier technologies (like C) may increase their production to be

able to compete with cheap imports →increase in emissions

Table 6: Equilibrium emission levels in tons over firms as import levels vary.

		OPG	**BROOKFIELD**	**FRINGE**
I=0	NOx	12,154	312	7,614
	SO2	44,521	0	0
	CO2	14,711,363	283,247	7,574,204
I=I	NOx	9,662	312	7,280
	SO2	36,364	0	0
	CO2	12,556,733	283,247	7,283,127
		OPG	**BROOKFIELD**	**FRINGE**

Air Emission Offset by Imports

- Emissions are nonlinear in imports.
- The least pollutant player is the Brookfield Renewable Energy
- The most polluting player is OPG.

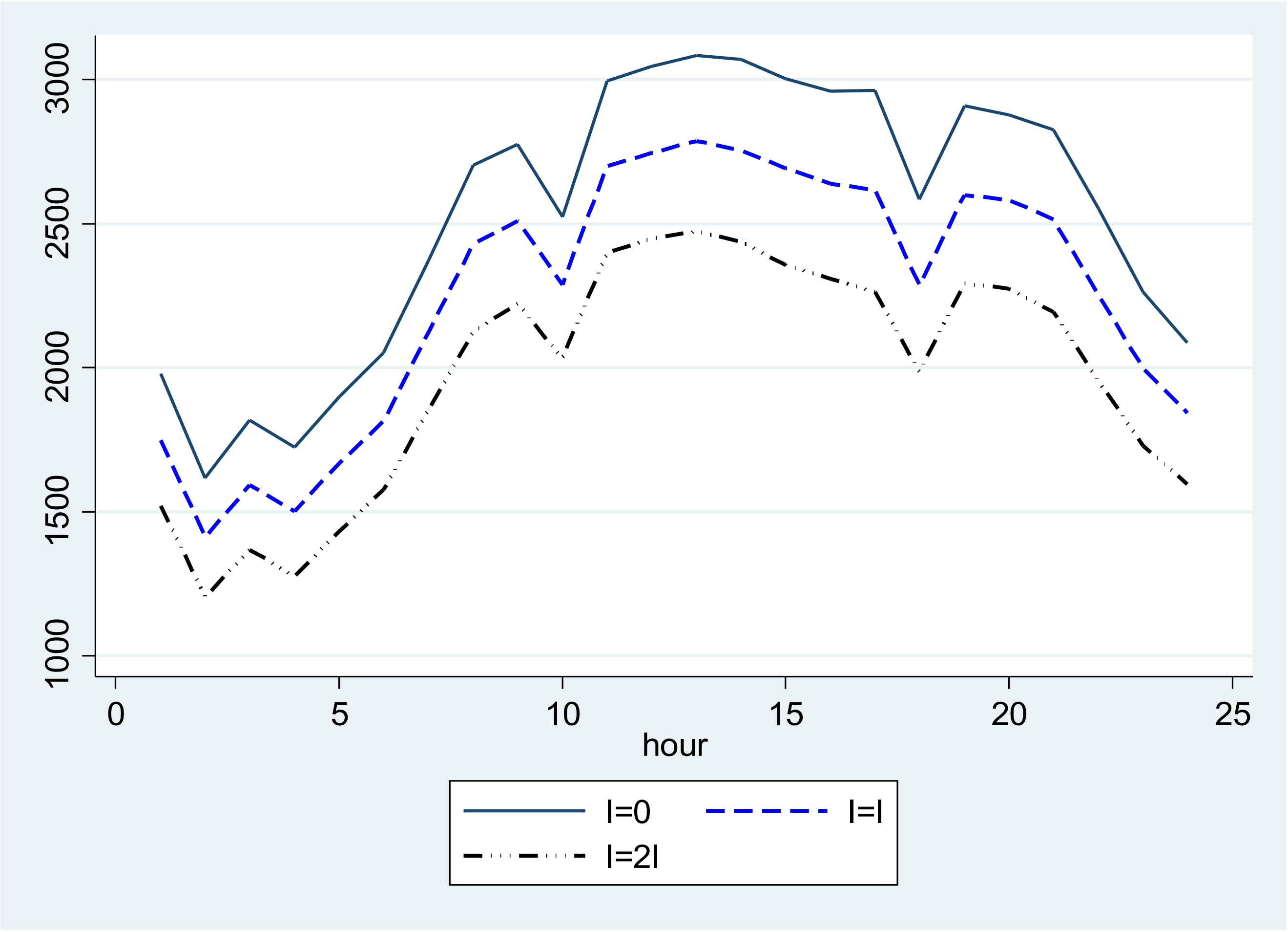
- The OPG is the dominant player with over 50% market share, has large hydro and nuclear units in production.
- The fringe players meet around 15% of the load and has mainly natural gas and oil fired production technologies.
- SO2 pollution is mainly due to the OPG as it is the only firm operating coal plants.
- Increase in the import levels has greater impacts on the OPG pollution levels than the rest of the players.

- The emissions by fringe players are moderate as a result of trade, but the reduction is less pronounced relative to the emission reduction caused by OPG.

Table 7: Total emissions in tons with respect to change in import levels

	NOx	SO2	CO2
I=0	20,080	44,521	22,568,814
I=I	17,254	36,364	20,123,107
I=2I	14,839	28,681	17,602,609

Figure 6: Average hourly CO2 emissions in ton (y-axis) by the hour of the day (x axis).



Extension: The Role of Exports

- Mainly examined the role of imports on market outcomes and air emissions.
- Explicit analysis of exports has been omitted because exports were implicitly modeled in the estimation of total market demand which is equal to Ontario demand plus export demand.
- Of interest to examine how a change in export demand would affect the firms' productions, market prices, and emissions levels.
- Fix the imports at the existing quantities and examine certain export scenarios to measure their impact in the market.

Table 8: Market outcomes and emissions in March 2008 with respect to change in export levels.

Export level	E=0	E=E	E=2E
Price ($)			
Average price	51.62	58.65	65.99
St. dev.	20.74	22.95	25.47
Skewness	1.82	1.81	1.75
Kurtosis	4.77	4.49	4
Demand quantity (MWh)			
Average demand	18,542	19,477	20,352
St. dev	1,593	1,628	1,663
Skewness	0.13	0.15	0.16
Kurtosis	-1.08	-0.99	-0.9
Total DWL ($)	30,212,212	27,913,605	19,466,709
Change in Welfare ($)	-	2,298,607	8,446,896
Total Emissions (ton)			
NOx	596.34	797.22	1048.23
S02	90.16	408.65	947.73
CO2	606,279.8	799,902.2	1,096,280.2

Table 9: Equilibrium total emission levels (in tons) in March over firms as exports vary.

		OPG	BROOKFIELD	FRINGE
E=0	NOx	30.94	8.57	556.83
	SO2	90.16	0	0
	CO2	23,583	7,772.8	574,924
E=E	NOx	138.8	12.2	646.2
	SO2	408.6	0	0
	CO2	134,480.6	11,082.9	654,338.7
E=2E	NOx	301.6	15.9	730.7
	SO2	947.7	0	0
	CO2	355,622.4	14,431.5	726,226.3

The Role of Exports

- All firms pollute more as the export demand rises.
- The significant polluters are the OPG, who is the sole source of SO_2, and the fringe firms, who emits the higher amounts of CO_2, from oil and gas fired generators.

- The impact of exports are more pronounced than the impact of imports (extreme prices, emissions.)

Table 9: Equilibrium total emission levels (in tons) in March over firms as exports vary.

		OPG	BROOKFIELD	FRINGE
E=0	NOx	550	28	616
	SO2	1,745	0	0
	CO2	653,038	25,674	628,704
E=E	NOx	888	28	704
	SO2	3,136	0	0
	CO2	1,162,208	25,674	704,510
E=2E	NOx	1,485	28	788
	SO2	4,960	0	0
	CO2	1,644,772	25,674	772,429

Imports versus Exports

- The average market prices are decreasing in import levels and increasing in export levels, and the rate of changes in prices are asymmetric.
- The average market prices in March are 63.55, 58.65, and 53.93 for I=0, I=I, and I=2I, resp. They are 51.62, 58.65, and 65.99 for E=0, E=E, and E=2E, resp.
- Given the actual exports, the change in import levels cause 7.7% price reduction from I=0 to I=I, and 8.1% price reduction from I=I to I=2I.
- Given the actual imports, the change in export levels lead to 13.6% price increase from E=0 to E=E, and to 12.5% price hike from E=E to E=2E.
- The highest and lowest average prices are observed under the exports scenarios than the imports scenarios.
- We observe the same pattern in emissions In the market the lowest and the highest NOx levels are observed under the cases E=0, and E=2E.

Conclusions

- New issues in wholesale electricity markets are examined: electricity trade and its impact on the air emissions and the social welfare.
- In an equilibrium model we have covered Ontario’s interregional and international trade as energy transfers are significant and there is a rich data set.
- We have modeled the Ontario wholesale market incorporating all of the active generators and their strategic reactions in a dominant firms and fringe suppliers setting.

Conclusions

- Our competition model has a high predictive power and outstrips the IESO predictions.

- Simulate the model with plausible scenarios incorporating no imports/exports and high imports/exports situations to measure the trade implications on the welfare and air quality.

- After constructing marginal cost curves and estimating market demand curve for each hour, we run the model to obtain the hourly production quantities of generators/firms, and then use the emission rates to calculate the amount of NO_x, SO_2 and CO_2 gasses released by each generator and firm.

- When the hourly imports double from the current levels, the CO_2 emissions decrease around 12.6%, and the market prices reduce 5.4%. If there would not be any trade, the CO_2, SO_2, and NO_x emissions would increase 12%, 22%, 16%, resp., and the average market price would go up 5.8%, and the price volatility would rise 12%.

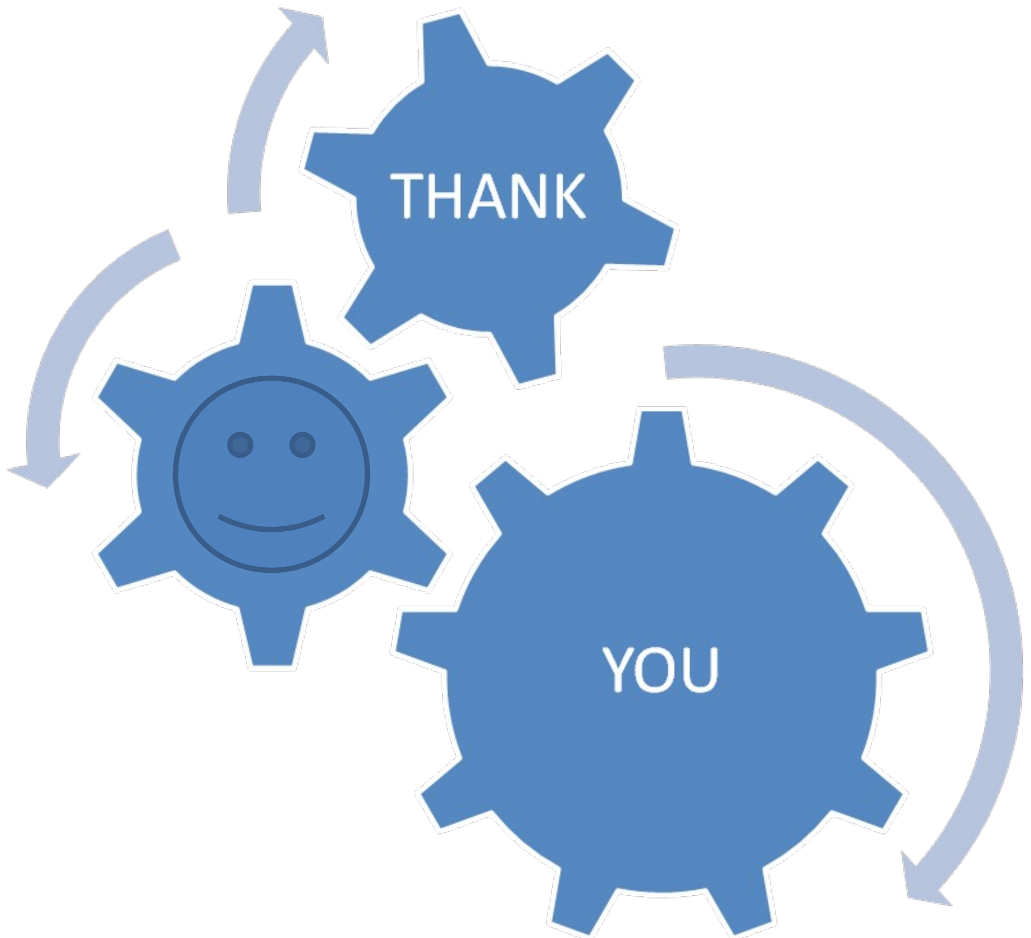
Conclusions

- The social welfare gain from the trade is around 50%.

- Measure the welfare loss when market prices are negative and find that the loss is very small—just 0.016% of the total welfare loss in a year.

- Find that relative to the import scenarios, the extreme market outcomes and emissions are pronounced under the export scenarios.

http://www.uoguelph.ca/~tgenc/Genc_Trade.pdf



Firm Level Predictions

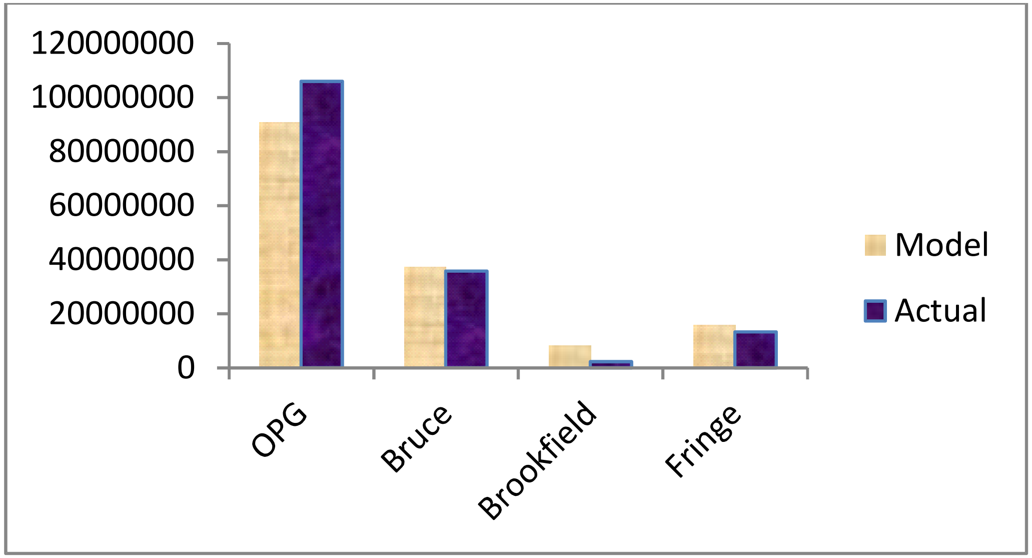
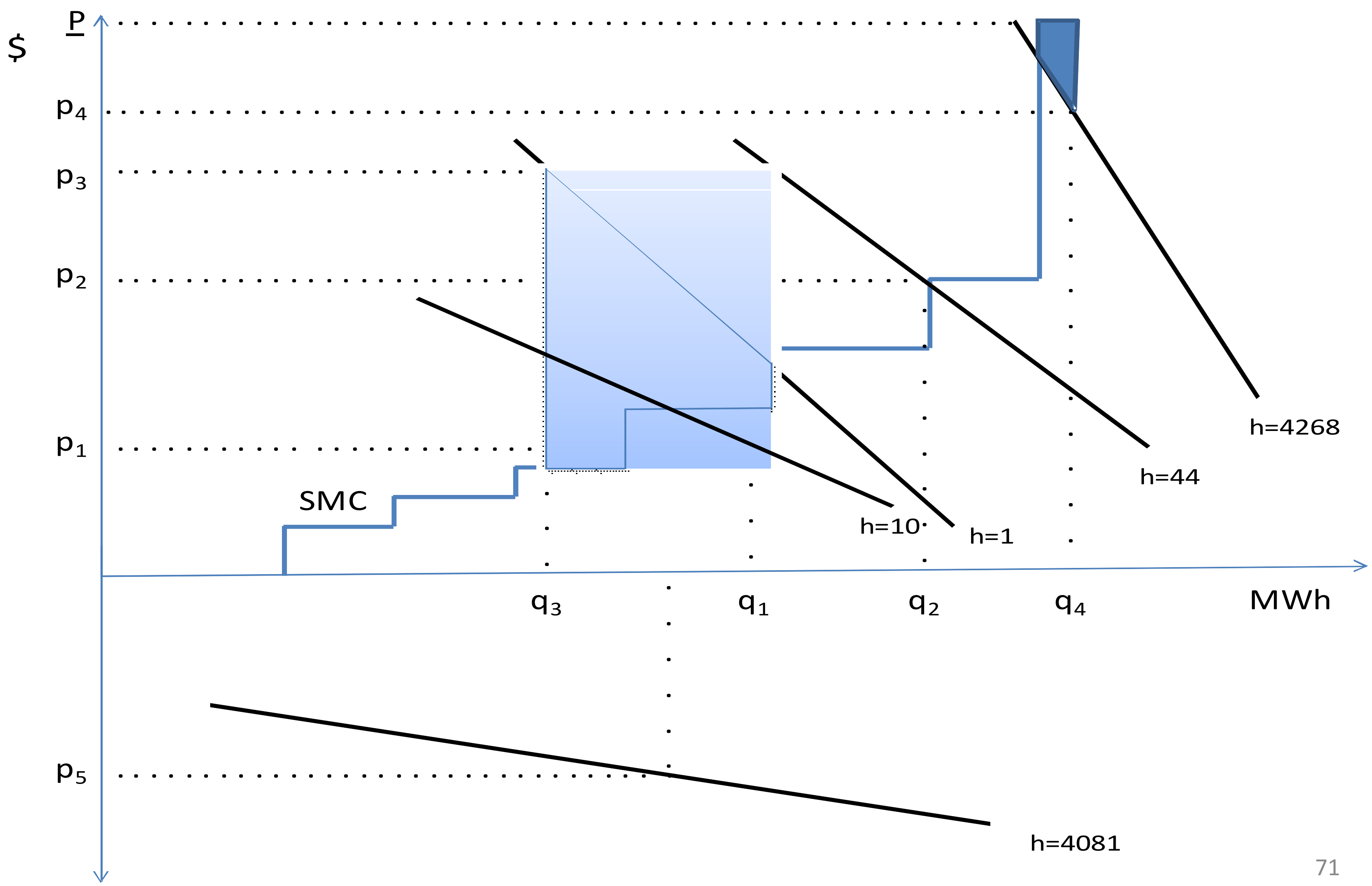


Figure 5: Actual versus predicted productions by firms (total MWh over the year).

Welfare Loss



Welfare Loss

- Given the market conditions mentioned above, we calculate the DWL for each hour from April 2007 to March 2008 in the Ontario wholesale market.

- We add these DW losses to find the total welfare loss (change in consumer and producer surplus) in the market.

- We find that the deadweight loss for the year is equal to **$215.77 million which is just 2.6 percent of the total energy cost** ($8.24 billion charged to the distribution companies in the year) in the wholesale market, which suggests that the imperfect competitive nature of the Ontario market is tolerable.

- The lowest DWL occurs in the Fall season in which the total energy cost is also the lowest compared to other seasons. Note that, surprisingly, the wind generated electricity is also the highest in the Fall.

Conclusions

- Derived MC curves of power producers
- Analyzed competitiveness of the Ontario wholesale electricity market
- Shown that the producers exercise unilateral market power
- Calculated social cost of oligopoly.
- Extensions

-------- Characterized the behavior.

-------- Modeling the market and addressing policy questions related to the environment and sustainability of the market.

-------- Calculated,

a) how much greenhouse gas emissions would be saved if the green technologies (wind, solar) would be adopted by market participants;

b) the likely impact of intermittent technologies (like wind turbines) on the market dynamics and the welfare of the society.

--- Found that ownership of 0 cost technology matters. Who should own the wind turbines, big players or small players?