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ORIGINAL RESEARCH

The cost impacts of a mandatory move to time-of-use pricing on residential customers: an Ontario (Canada) case-study

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Abstract Using 2008 hourly electricity data from 1,020 households in Milton, Ontario (Canada), this article asks and answers two questions: 'How do residential customers' total costs change as the result of a mandatory move from a traditional, flat-rate pricing structure, to a time-of-use one?'; and 'Are particular "kinds" of customers either "winners" or "losers" as a result of this move?' In response to the first question, 45% of customers have lower bills under a time-of-use regime (as compared with what they would have paid, had the previous two-tier regime continued, with their 'new' consumption patterns), while 55% of customers have higher bills. For 98.2% of customers, the difference in total cost is less than 5% (either way), and the average relative change is a 0.233% increase. In response to the second question, customers that have a relatively high level of consumption in either peak periods or wintertime are, in the absence of other differences, more likely to have higher bills under a time-of-use regime. Those households that consume higher quantities of electricity are more likely to have lower bills under a time-of-use regime, as compared with the two-tier regime. The article concludes by highlighting the equity implications of this finding and by identifying areas for future research.

Keywords Residential · Electricity · Time-of-use pricing · Canada

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Introduction

Advances in electricity industry technology, coupled with increasing concerns about the sustainability of power systems, are serving to increase interest in time-differentiated rates for electricity. Traditionally, electricity markets have, particularly for residential and other smaller-load users, had relatively little complexity in their tariff structures—customers paid the same 'per unit cost' for every kilowatt-hour of electricity they 'consumed'. Many maintain, however, that not only is this inefficient, but it is also unfair. If everyone pays the same price per unit, at every point in time, then those using electricity predominantly during low-demand periods are effectively subsidising those that are heavy electricity users during high-demand periods. A pricing regime that better reflects the so-called marginal cost of electricity production is justified on a variety of grounds (Dewees 2010; Faruqui et al. 2009; Stokke et al. 2010).

The growing deployment of interval meters (meters that record not only cumulative electricity consumption, but also time-stamped electricity consumption levels) offers the technological route for more widespread establishment of time-differentiated rates. Greater concern about the economic, environmental and social performance of electricity systems provides a catalyst for public debate about the same. As a result, discussion surrounding the desirability of new kinds of electricity tariffs for residential customers has grown in many jurisdictions (Faruqui et al. 2010, 31). Much of this discussion revolves around three general options: (1) 'time-of-use' rates, in which predetermined prices are different during distinct time periods (usually two or three such 'buckets', perhaps seasonally differentiated), with higher prices occurring during traditional 'high-demand' periods; (2) 'time-of-use plus critical-peak pricing' rates, in which a time-of-use regime governs for most of the time, but there are also a small number of additional hours during which advance notice would be given for significantly higher price periods; and (3) 'real-time pricing' rates, in which prices are not known in advance, but instead are determined by supply and demand in the market (e.g. Pollock and Shumilkina 2010).

With the widespread deployment of interval meters in Ontario (Canada), the key technological precondition for rate refinement is being put in place in an effort to 'create a conservation culture in Ontario and [to] become a leader in energy efficiency' (Ontario Ministry of Energy and Infrastructure 2009). The Province has also committed to putting residential customers on time-of-use rates (Government of Ontario 2009) with that transition now well underway, thus providing an ideal situation for observational studies. What is unique about our dataset is that households have been moved to time-of-use rates through government mandate, rather than an 'opt-in' strategy, as is often the case in much of the existing literature.

In Ontario, the new price incentives that are part-and-parcel of a time-of-use regime may well encourage behavioural changes. Indeed, this is a key motivator for the shift in policy. While we do not investigate the impact of a change in pricing upon consumers' electricity consumption behaviour in this article, this issue is part of our broader research plans. Our immediate question, however, is how this change in pricing regime will affect the 'bills at the door'?

Speculation regarding an answer to this question is present in Ontario. Utility representatives have suggested that the impacts will be modest. One report cited Toronto Hydro officials, who estimated that in the absence of any behavioural changes, electricity bills will 'rise by about 1 per cent' (Spears 2009). More recently, the Vice President of Marketing and Chief Conservation Officer at Toronto Hydro reported that about half of utility's customers then on time-of-use rates were 'seeing their bills increase or decrease by 2 per cent', but some were seeing larger swings (Blair Peberdy, quoted in Hamilton 2009).

More significant changes were also reported in the press. An article in the province's largest-circulation newspaper, for example, cited Clive Holloway, a 'professor of chemistry at York University' as saying that 'My estimations show that one can expect at least a 5-per-cent increase, but it is more likely to be 10 per cent or higher unless you restrict your activities considerably' (quoted in Hamilton 2009). Additionally, a number of representations to the Ontario Energy Board expressed concern about the potential impact: a group of agricultural representatives declared that time-of-use 'punishes' low volume users, which they estimated to be about one half of residential users (Ontario Federation of Agriculture 2008); and an individual citizen argued that lower- and middle-income individuals in smaller homes will end up being worse off (Smith 2008).[1] Given these perspectives, a systematic investigation would appear to be particularly timely.

Therefore, this article aims to answer the following question: How do residential customers' costs change as the pricing structure moves from a traditional, flat-rate regime, to a time-of-use one? Following from this, we also ask: Are particular 'kinds' of customers either 'winners' or 'losers' as a result of this move?

The context

The electricity system in Ontario (Canada)

Electricity systems in Canada are largely administered by the country's individual provinces (following the terms of the Canadian constitution). In Ontario—Canada's largest province, with a population of

[1] There have also been differences of opinion in other jurisdictions (e.g. CPUC 2010; Johnston 2009).

approximately 13 million people—electricity is supplied by a portfolio of resources, dominated by nuclear power (55.2% of total supply), hydropower (25.5%), natural gas (10.3%) and coal (6.6%; 2009 figures from IESO 2010a). Once a winter-peaking system (driven by heating and lighting demands), the system is now usually summer-peaking (driven by increased air conditioning demand in the summer, and replacement of electricity with natural gas for much heating in the winter) with maximum demand levels of approximately 25,000 MW and annual electricity consumption of about 150 GWh (IESO 2010b).[2]

Ontario's electricity market has been characterised as a 'hybrid market', with a mixture of mechanisms that includes flat rates, predetermined scheduled rates, fixed contracts and spot prices. For our purposes, we focus upon the residential marketplace, which is responsible for approximately one third of total electricity consumption. System-wide peak demand has been declining slightly recently, owing to conservation efforts and the economic recession (IESO 2009, 10), but the residential sector's contribution to this—estimated at 30.2% in 2005—is expected to continue to rise in both absolute and relative terms (OPA 2006, 12).

With the start of electricity restructuring in Ontario in 1998, new pricing models began to be used in the province. Residential customers, for example, became subject to the 'Regulated Price Plan'. Meant to recover the costs of supplying the entire set of low-use consumers with electricity (OEB 2010a, i), residential customers are subject to one of two sets of pricing arrangements. Most customers have continuously been on (and continue to be on) what has become known as the 'two-tier system'.[3] Sometimes called 'inverted blocks' in other jurisdictions, a unit of electricity is charged at one rate until a monthly threshold level is reached; beyond this threshold level, a higher rate is charged for every subsequent unit of electricity consumed. In Ontario, that threshold level has been higher in the winter (1,000 kWh/month) than in the summer (600 kWh/month), thus recognising the importance of the commodity for heating for some households, and for lighting for all households, during the year's coldest and darkest months.

With the increasing deployment of interval meters, more and more customers have been put on 'time-of-use' rates. In this arrangement, three periods—on-peak, mid-peak and off-peak—are defined. (They are different for each of province's two seasons: winter, 1 November to 30 April; and summer, 1 May to 31 October.) In both the two-tier and time-of-use systems, the rates are adjusted every 6 months by the province's energy regulator, the Ontario Energy Board. In the setting of these prices, the intention is both cost recovery and equity between the 'average' two-tier and time-of-use consumers, assuming no change in energy consumption patterns (OEB 2008, 4).

Analysing price differentials

There is a large amount of literature on the impacts of time-differentiated prices upon residential customers, much of which focuses upon elasticities and conservation impacts (for reviews, see Faruqui and Sergici 2010; and Newsham and Bowker 2010). Relatively fewer analysts have investigated the cost impacts, for end-use consumers, of moving from some kind of 'flat-rate' system to a 'time-of-use' one. A pioneering project was completed by Acton and Mitchell (1979, 17), when approximately 1,000 Los Angeles households were voluntarily placed on to a 'time-of-day' rate for a 30-month period; facing 'peak prices between 3 and 12 h per day 5 or 7 days per week', prices 'ranged from [US$0.05 to US$0.13]/kwh during peak hours and [either US$0.01 or US$0.02]/kwh during off-peak hours'. Considering what happens to costs when the new pricing regime is applied to pre-existing consumption patterns, the authors find that time-of-day rates 'increase [the] bills of most users who make no changes in consumption unless they have electric space heating' (Acton and Mitchell 1979, 37), 'although the changes are small' (Acton and Mitchell 1979, 30). Alternatively, when changes in consumption follow from the implementation of time-of-day rates, the authors conclude that larger customers benefit more, that is, the benefits (in absolute terms) grow as consumption grows. Presumably, those with swimming pools are particularly

[2] The 20 highest demand-days in Ontario have all occurred on weekdays in June, July or August, with peak demand between 2 PM and 6 PM (IESO 2010c).

[3] To this point, we have been calling this general pricing approach the 'flat-rate' approach, in order to be consistent with industry-wide terminology. As we now move our discussion to Ontario in particular, we use the term 'two-tier' to refer to the particular regime in use in the province.

adept at load-shifting and thus taking advantage of the new rates (Acton and Mitchell 1979, 32).[4]

Hartway, Price and Woo (1999) report that after a sample of 325 customers agreed to be put on to time-of-use rates in the US states of Oklahoma and Texas, their average annual savings were US$77 compared with a control group. This study demonstrated both 'load-shifting savings' as well as 'conservation savings'. Another noteworthy finding from this investigation is that most of the savings (more than 97%) was realised in the summer (though there was still some, though less, load-shifting and conservation in the winter; Hartway et al. 1999, 902).

Faruqui (2010, 3) notes that, as commonly developed under revenue-neutrality principles, dynamic pricing broadly (which includes, but is not restricted to, time-of-use rates) means that 'half of the customers whose load factors are better than average will see an immediate reduction in their bills *before* they make any adjustment to their pattern of electricity consumption' (emphasis in original). With load factor defined as the ratio of a customer's average demand to her or his peak demand, it is the 'peaky customer' (those customers with a share of peak load that is above the average) who will, in the absence of any change in behaviour, see an increase in costs. Faruqui complements these theoretical reflections with results from an unnamed 'large urban utility'. An analysis of low-income customers at this utility reveals that 80% of them would gain from dynamic pricing, with a modest amount of demand response (behavioural change in wake of the change in tariffs) that share of 'winners' would increase to 92% (Faruqui 2010, 9–10).[5]

Before the more widespread deployment of interval meters in Ontario, the Ontario Energy Board (OEB) approved a number of pilot studies in order to advance understanding of their potential impact in the Province. The first placed a number of Ottawa, Ontario households on one of three rate regimes: time-of-use pricing; time-of-use pricing plus critical-peak pricing or time-of-use pricing plus critical-peak rebate (OEB 2007). Researchers found that electricity bill reductions 'from [time-of-use] pricing averaged 3% across all participants compared with bills based on two-tiered ... prices. Seventy-five percent of project participants paid less on [time-of-use] prices than they would have on two-tiered... prices, ranging from a few cents for small volume users to [C]$6 per month for larger volume users.' (OEB 2008, 8) Brockway's analysis of this work suggests that, for time-of-use prices only, the average savings was about 2%, with the largest savings being about 14% and the largest increase about 12% (Brockway 2008, 76). If the conservation effect is added into the bill calculation, then 93% of participants paid less for electricity on time-of-use prices compared with the two-tier prices (OEB 2007, 7). Brockway (2008, 75) notes that the 'Ontario evaluators did not break out bill impacts by income or other participant characteristics'.

Navigant Consulting (2008) analysed the results of a pilot in Newmarket, Ontario, where 220 homes were put on to time-of-use pricing for a 1-year period (in addition to a subset of participants being given remotely controllable thermostats). Comparing the bills that these participants paid on time-of-use rates from September 2006 to August 2007, with what they would have paid on the two-tier system, it was found that 66% paid more under time-of-use rates, with the largest increase being 13.4% (of commodity costs); the other 34% paid less under time-of-use rates, with the largest saving being 7.4%. On average, customers' commodity prices (when on time-of-use rates) were 'slightly' higher—'just under 2%' (Navigant 2008, iii). An explanation offered is that the sample had consumption levels lower than the provincial average—as such, more of their consumption would fall below the price threshold in the two-tier system.

Hydro One (2008) completed a pilot of 330 residential, farm and small general service (under 50 kW) customers that were put on time-of-use rates for a period of 4 months—from May 2007 to August 2007. Note that this Hydro One study did not report disaggregated results; however, 303, or almost 92%, of these customers were residential. Comparing what their bills would have been under these two pricing regimes (two-tier and time-of-use), 76% of participants had lower bills on time-of-use—on average C$6 a month; the other 24% had higher bills—on average C$2 a month. For the group as a whole—across the 4-

[4] For a broader review of studies from this time period, see Aigner (1985). For a review of discussions that date back to the nineteenth century on this issue, see Hausman and Neufeld (1984).

[5] Space limitations preclude a summary of all relevant studies. Additional investigations that may be of interest to the reader include eMeter Strategic Consulting (2009); Faruqui and Wood (2008); and Messenger (no date given).

month period—the bill was C$60.30 under time-of-use, while it would have been C$64.58 under the two-tier system. This is a savings of C$4.28 or just over 7%. On average, August showed the largest absolute and relative difference and June the smallest (both absolute and relative).[6]

Reflecting upon their experiences with a variety of pilot projects, the Ontario Energy Board made a number of 'preliminary observations' on the consequences of more widespread use of interval meters and associated dynamic pricing regimes. These included the following: 'impacts on the total consumer bill of switching to [time-of-use] pricing depended on individual consumer conservation responses and their average electricity costs (i.e. the relative proportion of their consumption that was in each tier before switching to [time-of-use])' (OEB 2008, 6). Providing some more granularity to such comments, the aforementioned Hydro One study observed: 'Depending on individual usage patterns, selected customer groups under the ... [time-of-use] rates could be better off or worse off. Customers groups that would likely be negatively affected by the ... [time-of-use] rates include residential customers with low electricity consumption [and] customers who stay at home during peak hours' (Hydro One 2008, 5).

From this review of the literature, we take two key messages. First, there is value in a systematic investigation into the Ontario case, for there are diverse positions with respect to the impact of this rate regime change. What limited analysis has been done, moreover, has often examined data for less than a year. We investigate—as is described more fully in the next section—data from across an entire calendar year. Moreover, our study also answers Brockway's call (2008, 83) for more research with respect to the likely bill impacts of new tariff structures motivated by the increased deployment of interval meters, in particular, with respect to how different kinds of customers might end up better off or worse off. As she puts it: 'Regulators will want to understand the bill impacts on classes of customers and subgroups within each class, however, if for no other reason than to gauge the likely public response to approving (or mandating) the investment and related tariffs' (Brockway 2008, 72; see also Alexander 2007).

[6] Again, space limitations preclude a systematic review of all relevant studies. See, also, Simmons (2010).

Second, any study that uses data from a broad population—not, that is, a selected population that explicitly 'opted in' to a pilot study—has the potential to overcome potential self-selection biases and thus provide insights that may have broader applicability (Train 1991). Our sample, which we describe more fully in the next section, is made up of residential customers with interval meters, all of whom were moved from the two-tier system to the time-of-use system as part of a utility's plan for moving all of its customers in this way. As such, our sample may be somewhat more representative of what happens when meters are 'rolled out' more broadly (compare with Allcott and Mullainathan 2010). Of course, our analysis is by no means the final word on this topic—with more data come the opportunity for more investigations, including additional questions—but we nevertheless feel that such a study has the opportunity to move the debate forward.

Methods

In this section, we describe the means by which the sample was selected. We also present information about the Ontario electricity market conditions (prices, in particular) during the period under study.

All data were provided by Milton Hydro Distribution Inc. (Milton Hydro), and all were anonymous as required under a research protocol approved by the University of Waterloo's Office of Research Ethics. Milton Hydro is one of Ontario's 80 local distribution companies, each of which is responsible for the delivery of electricity to end users in the province's urban areas. Milton Hydro serves the town of Milton. Located approximately 50 km west of Toronto, Milton is Canada's fastest-growing community with a population of 54,000 (2006). Milton Hydro has been at the forefront in the province with respect to the deployment of interval meters and innovative conservation and demand management programmes (Andersen 2010, 4). Indeed, as of 31 December 2009, 99.7% of the utility's eligible customers had interval meters installed; 22,260 of those customers (which represented 86.7% of those with interval meters installed) were being charged time-of-use rates (Milton Hydro Distribution Inc 2010).

Our selection strategy was meant to satisfy a number of criteria important for our broader research programme—not all of which were imperative for the investigation carried out, and reported upon, in this article. One author (IR) worked with Milton Hydro to generate the sample. We initially identified residential accounts that had hourly electricity data available for at least 2 years (2007 and 2008) and that were not an apartment or condominium. This yielded 10,394 candidate accounts. We then explicitly selected two kinds of households—those that were a participant in the Province of Ontario's residential demand response programme (known as PeakSaver) during 2007 or 2008 (n=205) or those that had participated in an April 2006 telephone survey conducted by a consultancy on behalf of Milton Hydro (n=365). Collectively (given that there were seven households that met both criteria), this generated 563 households for our sample. We then selected from the remaining 9,831 accounts an additional 205 that best matched the PeakSaver homes on the basis of time-of-use start date, neighbourhood location and consumption. Finally, we selected another 529 households (from the remaining 9,629 accounts), on the basis of the number of times that the name on the account had changed (thus serving as a proxy for the ownership turnover rate in the property); we selected those with the lowest values. This is how we generated our sample of 1,297 households. Of note is the fact that energy consumption patterns were used to construct 16% of the sample; moreover, in these cases, we only used them to match, approximately, PeakSaver households by comparing total annual electricity consumption.

For the investigation in this article, we subsequently eliminated those households that had gone on to time-of-use pricing after 31 December 2007. (The entire sample went on to time-of-use pricing at different times between 7 October 2005 and 29 April 2008.) We thus had 1,020 accounts to examine. These households' hourly electricity consumption data, for the period 1 January 2008 to 31 December 2008, were downloaded to a MS-SQL Server database (version 10.0.2531.0) for data mining and further analysed using Microsoft Excel 2007 (version 12.0.6524.5003).

We conclude this section with information about the prices that were in place during the period under investigation. In Table 1, we lay out information about both systems: columns 2, 3 and 4 provide information about the 'two-tier' system, namely, the unit cost (per kilowatt-hour) below the seasonal threshold, the unit cost (per kilowatt-hour) above the seasonal threshold, and the amount of electricity that serves as the threshold; columns 5, 6 and 7 provide information about the 'time-of-use' system, namely, the unit cost (per kilowatt-hour) at each of the on-, mid- and off-peak periods. And, Table 2 provides information regarding when these periods occurred, in both winter and summer. These data were also included in the MS-SQL Server database.

Finally, while most of the literature analyses commodity prices (that is, the difference in the costs of the electricity itself, in each of the two pricing systems), we also incorporate the non-commodity charges associated with the consumer's actual expenditures. In Table 3, we list the additional charges that would 'show up' on the residential customer's bill.

Results

A screening of our data raised an issue that required immediate attention—namely, a number of accounts

Table 1 Electricity commodity prices associated with two-tier system and time-of-use system, Ontario, 1 January 2008 to 31 December 2008

Time period	Two-tier system			Time-of-use system		
	Unit cost (C$/kWh), below threshold	Unit cost (C$/kWh), above threshold	Threshold (kWh)	On-peak unit cost (C$/kWh)	Mid-peak unit cost (C$/kWh)	Off-peak unit cost (C$/kWh)
1 January 2008 to 30 April 2008	0.050	0.059	1,000	0.087	0.070	0.030
1 May 2008 to 31 October 2008	0.050	0.059	600	0.093	0.073	0.027
1 November 2008 to 31 December 2008	0.056	0.065	1,000	0.088	0.072	0.040

Table 2 Time-of-use periods, weekdays, Ontario, 1 January 2008 to 31 December 2008

Time of day	Winter (1 January 2008 to 30 April 2008; and 1 November 2008 to 31 December 2008)	Summer (1 May 2008 to 31 October 2008)
Midnight to 7 AM	Off-peak	Off-peak
7 AM to 11 AM	On-peak	Mid-peak
11 AM to 5 PM	Mid-peak	On-peak
5 PM to 8 PM	On-peak	Mid-peak
8 PM to 10 PM	Mid-peak	Mid-peak
10 PM to midnight	Off-peak	Off-peak

Note: Weekends and holidays are, across all 24 h of each day, ‘off-peak’

had ‘zero’ entries (that is, the value entered for a particular hour is 0.000 kWh). After consultations with Milton Hydro, we decided to keep these entries in the dataset, for without additional information (through, for example, surveys or interviews), we did not know if the zero value represented ‘zero consumption of electricity’ in a house that was occupied (or at least owned by someone) or if the zero value represented some kind of ‘reporting error’ (for example, a failure to send the consumption value from the meter to the data collection point or customer tampering with the meter). Table 4 provides a frequency chart of the zeros found. As a reminder, for 1,020 households, the complete dataset for 2008 has 8,959,680 entries. With a total of 3,325 zeros across 2008, the values presented in Table 4 are, collectively, a relatively small part of our total data set—less than 0.04%.

Table 5 presents some basic information about electricity consumption among the 1,020 households in 2008. Figure 1 then presents information about these households’ hourly consumption patterns by season.

In Fig. 2, we have examined both ‘commodity costs’ (Table 1 schedule) and ‘total costs’ (Table 1 schedule plus Table 3 schedule), looking at relative (percentage) changes in a move from two-tier to time-of-use prices. Figure 3 presents ‘total costs’ looking at absolute changes. In both cases, a negative value indicates a reduction in costs as we moved from two-tier to time-of-use such that those towards the left-hand side of the graph are ‘winners’ under time-of-use rates. Similarly, those towards the right-hand side of the graph are ‘losers’ under time-of-use rates. These are the consumption patterns after time-of-use rates had been introduced, so any behavioural changes motivated by the introduction of the new price regime have taken place. In both Figs. 2 and 3, the curves cross the *X*-axis at the 45% mark meaning that 462 households pay less under the time-of-use regime (‘winners’) while 558 pay more (‘losers’).

Table 3 Additional electricity charges, residential customers in Milton, 1 January 2008 to 31 December 2008

Charge (C$ per kWh, unless otherwise indicated)	1 January 2008 to 30 April 2008	1 May 2008 to 31 December 2008
Customer charge (per month)	16.13	16.02
Distribution	0.0133	0.0133
Transmission network	0.0056	0.0046
Transmission connection	0.0045	0.0043
Regulated price plan administration (per month)	0.25	0.25
Wholesale market service	0.0062	0.0062
Debt retirement charge	0.0070	0.0070
Total fixed charges (per month)	16.38	16.27
Total variable charges	0.0366	0.0354
GST rate	5%	5%

Table 4 Frequencies of zeros in the dataset, 2008, by month

Month	Number
January	193
February	12
March	13
April	248
May	111
June	65
July	21
August	355
September	244
October	1,454
November	606
December	3

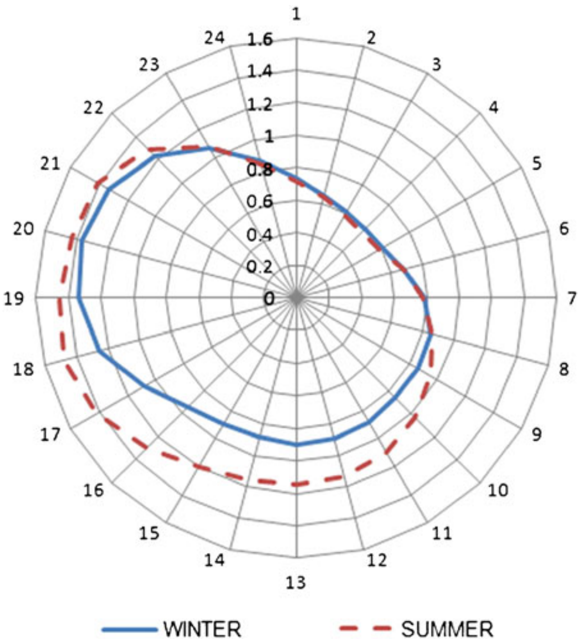


Fig. 1 Average seasonal electricity consumption (kilowatt-hour), by hour, selected Milton households, 2008 (n=1,020)

The data have been disaggregated by 'season' (as defined by the Ontario Energy Board) in Fig. 4. With the winter curve to the left of the summer curve (and the curves crossing the X-axes at the 23% and 59% marks, respectively), there are more than twice as many 'losers' with respect to the move in the wintertime, as compared with that in the summertime.

In Fig. 5, we see that as consumption rises, the chance of a householder being a 'winner' also increases. As a reminder, those values above the X-axis are 'losers' (for they have an increase in their costs as the prices move from the two-tier system to the time-of-use system) and those values below the X-axis are 'winners'. Figure 6 breaks this out by season. And, as Fig. 7 reveals, those with both a smaller and a larger share of their total consumption in winter appear to be more likely to be a 'winner'.

Trendlines were created using third-order regression equations for Figs. 5 and 6 (as three deflection points were likely at (0,0), the average consumer and the high consumer) and second-order regression equations for Figs. 7, 8 and 9 (as (0,0) was not a plot point). The associated R^2 values are reported. Paired two-tailed t tests are reported for Figs. 2, 4 and 6 and unpaired, two-tailed t tests for Fig. 9.

Table 5 Electricity consumption information, selected homes in Milton, ON, 2008 (n=1,020)

	Winter	Summer	Total
Average (kWh)	4,042	4,566	8,607
Minimum (kWh)	426	187	613
Maximum (kWh)	23,473	14,579	31,412
Standard deviation	1,785	1,939	3,508

For the sample as a whole across 2008, 19% of the electricity was consumed during peak periods, 26% during mid-peak periods and 55% during off-peak periods. This compares with the province's 'typical' residential load profile of 20% of electricity consumed during peak periods, 26% during mid-peak periods and 54% during off-peak periods (OEB 2010a, 19). Figure 8 reveals that those who consume a smaller share of their electricity during on-peak hours are more likely to be 'winners' with the move from two-tier to time-of-use pricing.

Discussion

Before analysing the results from our previous section, we remind the reader that we are examining consumption data for households that have already been put on to time-of-use rates. Consequently, the differences between the two rate regimes compare what was paid (under time-of-use rates) with what would have been paid (under two-tier rates) with the same consumption pattern. Recognise that the move

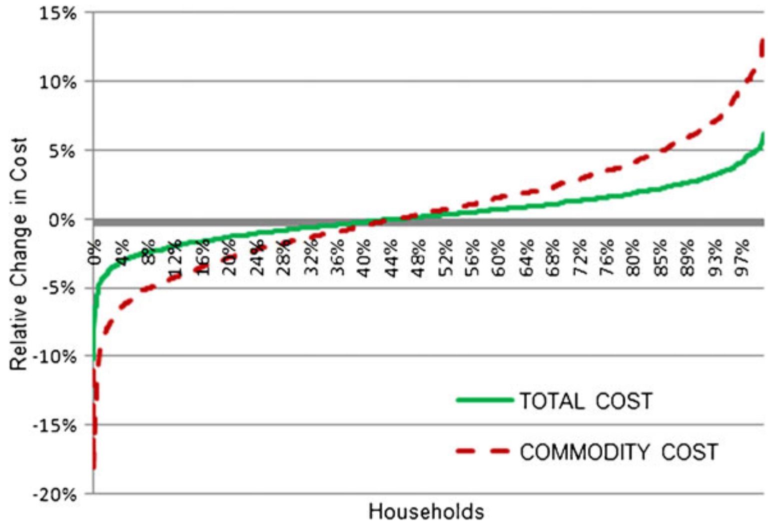


Fig. 2 Relative change in electricity costs, time-of-use system versus two-tier system, selected Milton households, 2008 (n=1,020). Groups are statistically different at $p<0.01$

from two-tier pricing to time-of-use pricing may have encouraged a change in consumption patterns. Additionally, recognise that our discussion relates to the experiences of these 1,020 households; in the third section of this article, we reviewed how this particular sample was constructed.

First, we asked whether these residential customers' costs change as a result of the change in pricing structure. Figures 2 and 3 answer this question. We found that customers' costs may go up (just over one half of the sample we examined) or may go down (just under one half). We also found that the percentage changes in the monthly electricity bill are, for the most part, relatively small. For 98.2% of the sample (1,002/1,020 households), that change was within 5%. Of the remaining 1.8%, ten of the 1,020 households saw increases above 5%, and eight of the 1,020 households saw decreases greater than 5%. In absolute terms, for most households (79.0%), it is a difference of less than C$24 across the year (on average C$2 per month). For those 21.0% of the sample for whom it was more than C$24, 115 of the 1,020 households saw increases, with one household experiencing an increase of C$66.13; 99 of the 1,020 households saw decreases, with one household finding savings of C$236.84.

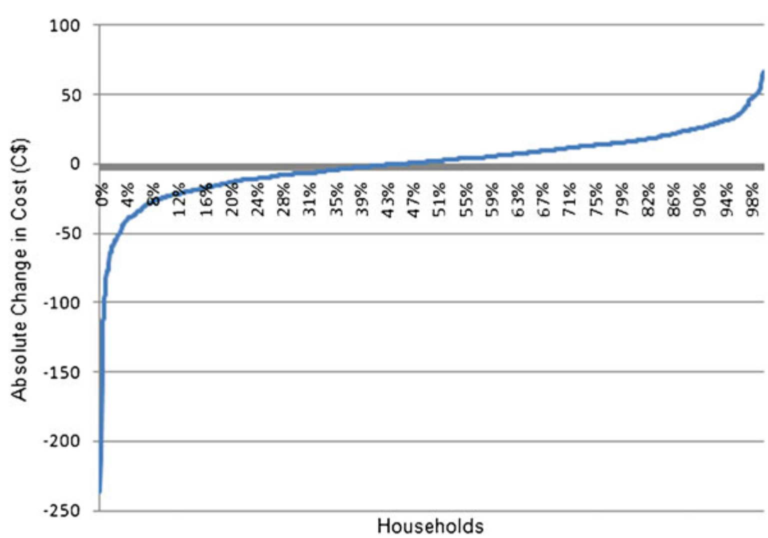


Fig. 3 Absolute change in electricity costs, time-of-use system versus two-tier system, selected Milton households, 2008 (n=1,020)

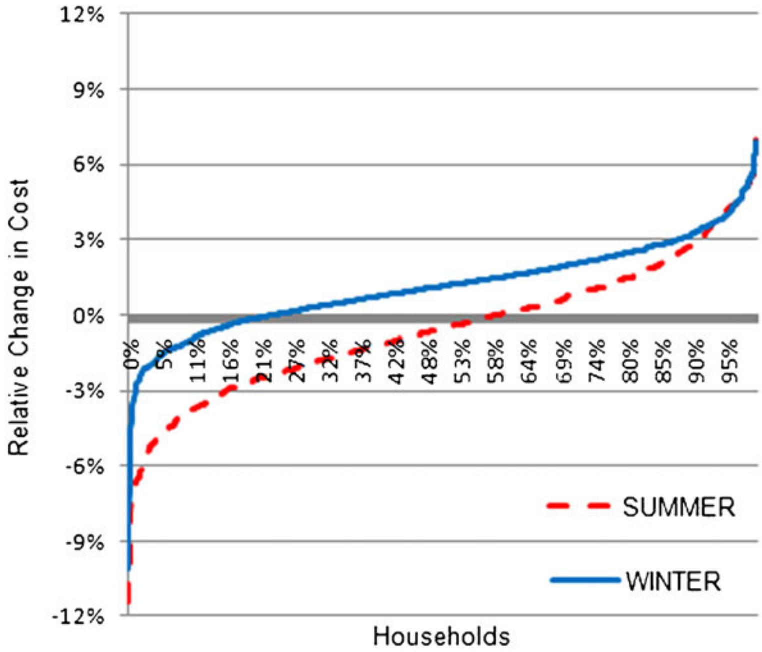


Fig. 4 Relative change in electricity costs, time-of-use system versus two-tier system, by season, selected Milton households, 2008 (n=1,020). Groups are statistically different at p<0.01

Unlike some in the literature, we focused upon the total costs that would be ‘seen’ by households, rather than the commodity (electricity) costs that are the values that change between the two pricing regimes. We did not distinguish between these two kinds of costs in Fig. 3 because they are identical in each. In Fig. 2, we see how a singular focus upon the commodity costs would cause the percentage differences to be larger.

Second, we asked whether customers who are ‘winners’ or ‘losers’ might be distinguished by particular characteristics. Figure 5 shows that, as total

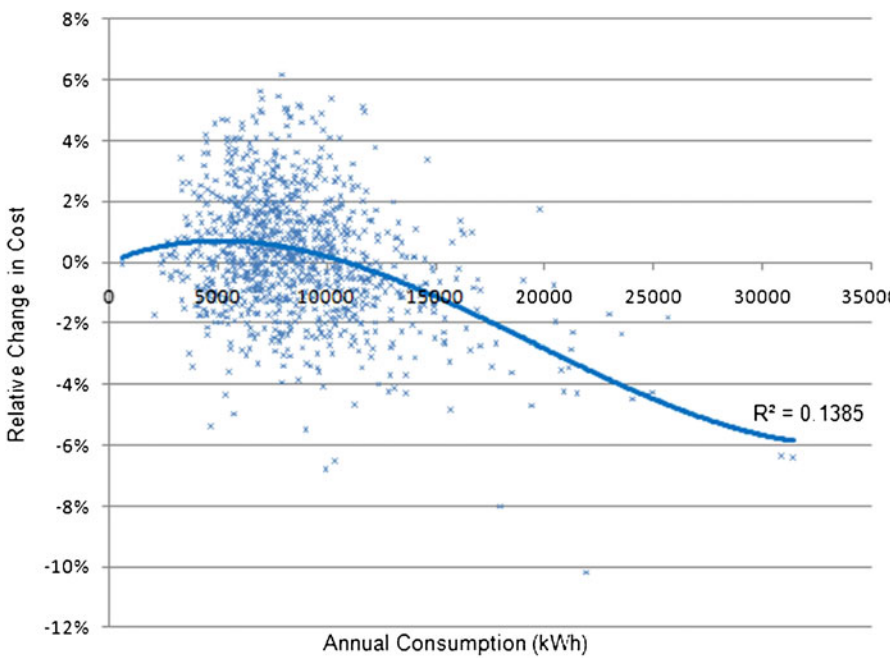
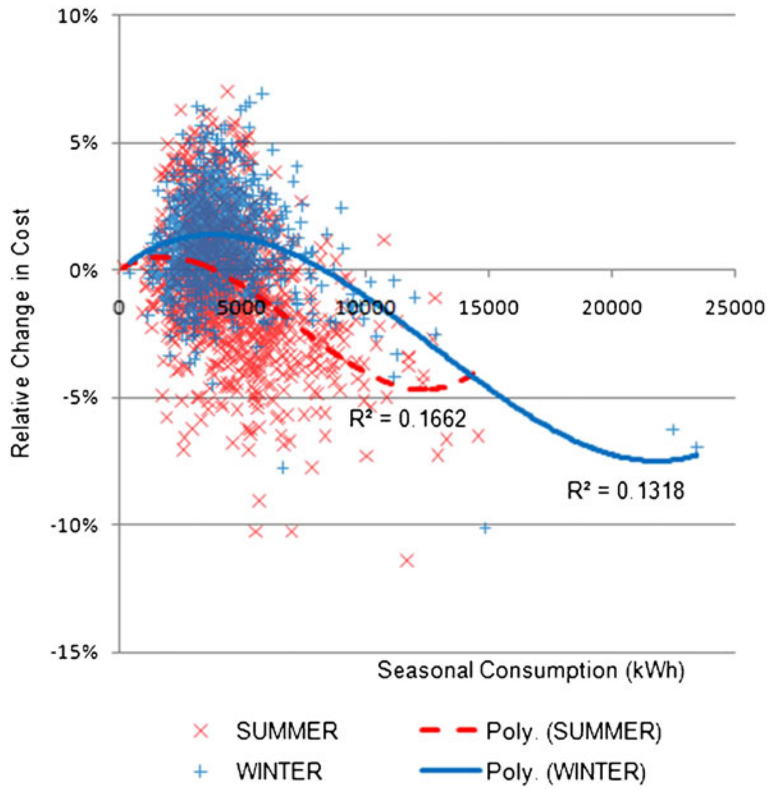


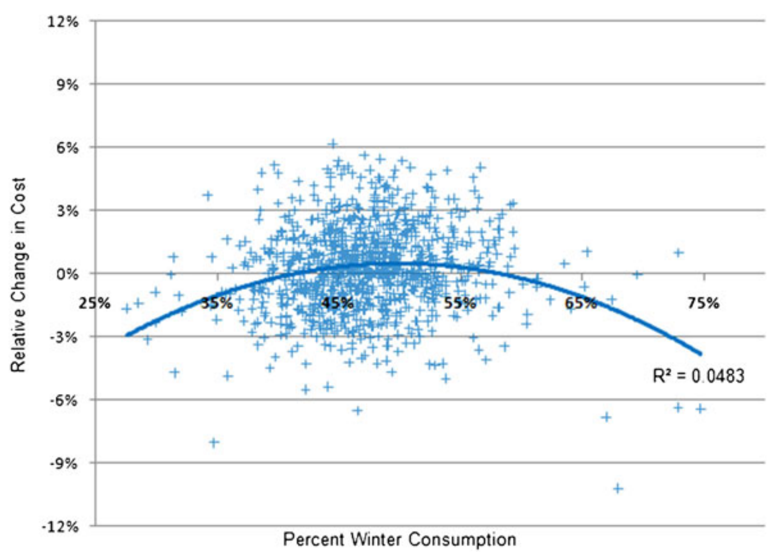
Fig. 5 Relative change in electricity costs, time-of-use system versus two-tier system, by electricity consumption levels, selected Milton households, 2008 (n=1,020)

Fig. 6 Relative seasonal change in electricity costs, time-of-use system versus two-tier system, by electricity consumption levels, selected Milton households, 2008 (n=1,020). Groups are statistically different at p<0.01



consumption increases, the prospects of being a 'winner', rather than a 'loser', also increase. While the graph does not 'peak' (on the left) to a dramatic extent, there is clearly a rise above the X-axis. Towards the right of the graph, however, the trough is more noticeable. Granted, there are fewer data points at the higher consumption levels, but it is nevertheless the case that those with higher consumption levels are more likely to see reduced costs following the move to time-of-use rates. Indeed, the

Fig. 7 Relative change in electricity costs, time-of-use system versus two-tier system, by percentage winter consumption, selected Milton households, 2008 (n=1,020)



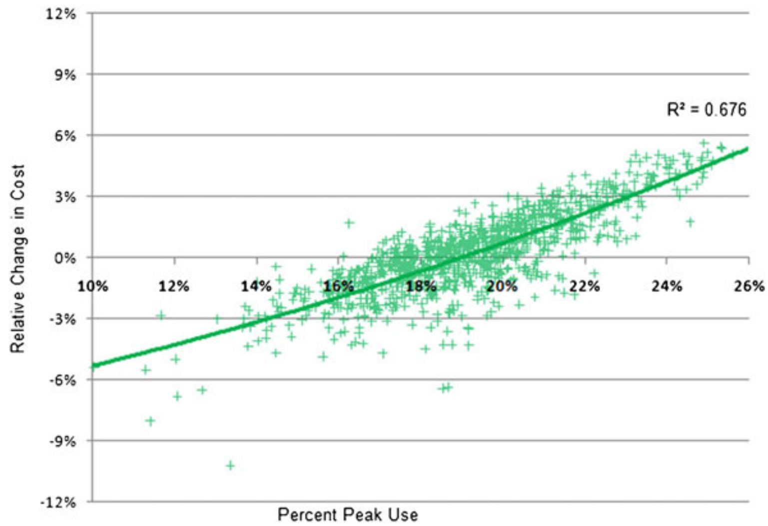


Fig. 8 Relative change in electricity costs, time-of-use system versus two-tier system, by percentage peak use, selected Milton households, 2008 (n=1,020)

16 highest consumers all saw savings, as did 30 of the highest 33 consumers.[7]

Figures 4, 6 and 7 allow us to explore whether the season in which most consumption takes place might be a predictor of 'winning' or 'losing'. Figure 4 shows that there are many more losers in the wintertime—that is, for many more households, costs for those 6 months increase as they move from two-tier to time-of-use prices. Given the higher threshold value in the two-tier system (that is, consumption must rise to 1,000 kWh per month before the higher unit charge is imposed, as compared with 600 kWh per month in the summertime), this is not particularly surprising. As such, we might expect those who consume most of their electricity in the wintertime to be losers following the change. But, Fig. 7 suggests that the answer may not be so simple. As the share of electricity that is consumed in the wintertime increases, households are more likely to become 'losers'. But, at a relatively high level (past 51.5%), the pattern is reversed, so that, eventually, those who are consuming more than 59% of their electricity in winter are actually better off under time-of-use rates. While this seems counter-intuitive, Fig. 6 reminds us to consider the impact of 'total consumption'. The four values in the lower right-hand part of the graph in Fig. 7 are all large users of electricity, across the year as a whole (from left to right, they consumed 9,934, 21,883, 30,871 and 31,412 kWh in 2008, respectively). As such, it may well be the impact of 'total consumption' is exercising an influence upon the shape of the curve in Fig. 7.

Figure 8 allows us to explore the impact of when, across the hours of the day, electricity is used, and whether this affects changes in costs. The graph is as we would expect: those who use more electricity, relatively, during peak hours are more likely to be losers when the pricing regime moves from two-tier to time-of-use. Following our efforts to consider the impact of multiple factors in our investigation of seasonality, Fig. 9 adds 'total consumption' to this present investigation. From this, we again see that the latter has an impact. Generally, as total consumption increases, the line in Fig. 9 shifts down—thus as consumption increases, cost decreases for the same relative peak electricity use.

Summary and conclusions

The move from a two-tier pricing system to a time-of-use pricing system creates changes in residential householders' total electricity costs as shown through

[7] Future investigation of homes with electric heat would be worthwhile. Milton Hydro was able to identify three homes in our sample that had self-reported the presence of electric heat in their homes. There may have been more, but we were not able to determine that. Though the sub-sample is extremely small, it is interesting to note that these three homes all had large consumption values (ranging between 21,883 and 31,412 kWh for the year), with more than two thirds of that consumption in the winter. Each house was a 'winner', moving from the two-tier rate to the time-of-use rate, with absolute savings ranging from C$205.76 to C$236.84 (representing relative changes of 6% to 10%).

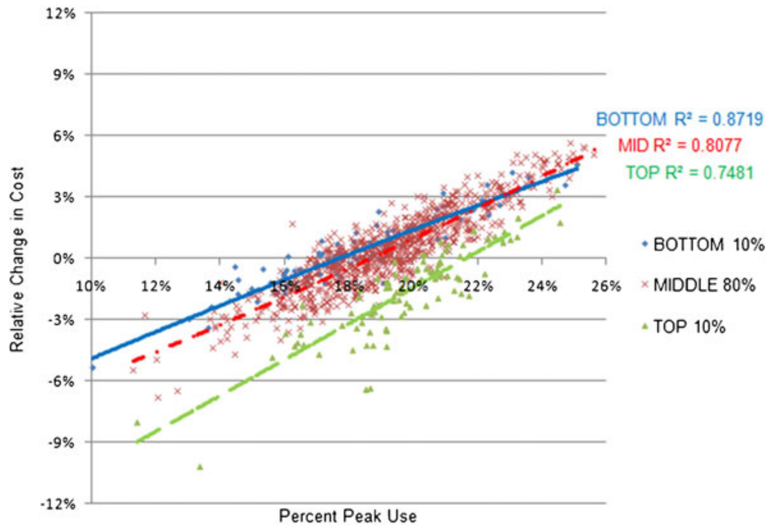


Fig. 9 Relative change in electricity costs, time-of-use system versus two-tier system, by percentage peak use and categorised by annual consumption (top 102 households, middle 816 households, bottom 102 households), selected Milton households, 2008 (n=1,020), p values of unpaired, two-tailed t tests, *top-middle* p=3.4E-17 (p<0.01), *top-bottom* p=1.1E-11 (p<0.01), *middle-bottom* p=0.11

our examination of data from 1,020 households, across a period of 1 year (2008), in Milton, Ontario. As expected there are 'winners' (paid less) and 'losers' (paid more), but those changes, for the vast majority of households, are not as dramatic as some have suggested. The average of the percentage change in household expense is an increase of 0.233%.[8]

On balance, consumers of larger quantities of electricity in our sample are more likely to be 'winners' than consumers of smaller quantities of electricity in our sample. While the broader literature is not unequivocal regarding this relationship, it should come as little surprise for our investigation in Ontario: the two-tier system 'punishes' larger users, for the per-unit consumption charge increases once the household is beyond a certain consumption threshold. There is no such threshold in the time-of-use system. Thus, while we say it is not a surprise, that does not mean that it is not worthy of attention. Clearly, there are equity consequences when larger consumers benefit more than smaller consumers, even when both groups have the same share of peak electricity use. Because larger users often (though not always) occupy larger homes and have larger incomes, this is an issue worthy of further consideration. Indeed, if larger users end up with lower bills, they may be encouraged to use more electricity (compare with Greening et al 2000; for work on the 'rebound effect' more generally, see, for instance, Sorrell et al. 2009). In response, hybrid systems that combine 'flat-rate' for small consumers and tiers beyond a particular threshold have been proposed (compare with Faruqui et al. 2009), and they should be examined in the Ontario context.

Our other recommendations relate to additional research that could further develop the analysis undertaken in this article. More specifically, we highlight two issues. First, as experience with time-of-use rates grows (particularly in Ontario, given the Government's targets, as described in the second section of this article), there is increasing opportunity to analyse financial impacts upon householders. Indeed, as sample sizes inevitably increase, the opportunity to do more rigorous investigations also grows. As our analysis in the fifth section of this article reveals, our initial forays into both pulling out particular characteristics of interest, and seeing how these characteristics work in combination, are indicative of the type of study that could continue in the future.

And second, the impact of rate changes upon electricity consumption behaviour is also worthy of investigation. Hourly electricity consumption data from both before and after the move from two-tier to time-of-use rates present the opportunity to

[8] This represents an 'average of the averages'. The total absolute change, across all 1,020 accounts, is a 0.008% increase. Moreover, it is important to recognise that not included within this are the costs of the infrastructure associated with the move towards dynamic prices, that is, the widespread deployment of interval meters and a supportive environment.

determine the extent to which (and the ways in which) prices motivate behaviour. Data from before the move to a time-of-use regime would also permit an analysis into the extent to which a pricing regime change would result in 'natural winners' and 'natural losers' (that is, in the absence of any behavioural change). Again, with increasing amounts of data being generated in Ontario (and elsewhere), by virtue of more widespread installations of interval meters, the opportunity to study this is more likely to arise.[9]

In any case, this article has aimed to advance the debate regarding the impact of a move to time-of-use rates, with a particular emphasis upon the Province of Ontario. While we have, in this section, identified avenues for further research, we nevertheless feel that, by analysing a large dataset over the course of an entire year, we have helped to enrich the present debate with data from households that have made the move from one pricing regime to another.

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[9] Future studies could therefore begin to address some of the limitations associated with our study. One not yet made explicit relates to the fact that our households had had different 'length of experience' with time-of-use rates—some for a matter of months, others for more than 2 years. Therefore, there may well have been varying degrees of knowledge about the new rate regime, as well as varying levels of 'rebound' back to old, pre-time-of-use, habits.

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