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The impact of informational feedback on energy consumption—A survey of the experimental evidence

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ABSTRACT

In theory, In-Home Displays (IHDs) can revolutionize the way utilities communicate information to customers because they can induce changes in customer behavior even when they are not accompanied by a change in electric prices or rebates for purchasing efficient equipment. IHDs provide consumers with direct feedback—real-time information on energy consumption and costs—and turn a once opaque and static electric bill into a transparent, dynamic, and *controllable* process. However, to what extent do consumers actually respond to the direct feedback provided by IHDs?

In this paper, we seek to empirically answer this question by reviewing a dozen utility pilot programs in North America and abroad that focus on the energy conservation impact of IHDs. We also review overall customer opinions and attitudes towards IHDs and direct feedback to the extent that this information is available from the pilot studies.

Our review indicates that the direct feedback provided by IHDs encourages consumers to make more efficient use of energy. We find that consumers who actively use an IHD can reduce their consumption of electricity on average by about 7 percent when prepayment of electricity is not involved. When consumers both use an IHD and are on an electricity prepayment system, they can reduce their electricity consumption by about twice that amount. In regard to demand response impacts, we find that the impact of time-of-use rates is augmented by direct feedback from IHDs.

1. Introduction

Imagine a world in which Joe Smith drives up to the gasoline pump in his large SUV, fills up his truck, and drives away without paying a dime. The gasoline is not free, but Smith won't know how much he purchased or how much he owes until a month later because he has a monthly account with the filling station. When his wife drives up to the pump in the family sedan, she goes through the same procedure; as does their high school senior, who drives up to the pump in her compact coupe. The Smiths get a combined bill a month later and don't know how the charges accumulated. Was it Joe's driving, his wife's driving, or their daughter's driving that accounted for the lion's share of the bill? What makes life even more interesting for the Smiths is that none of their cars have a speedometer or a gasoline gauge. They get no feedback at all on how to manage their gasoline bill.

Are the Smiths living in some type of parallel universe? No. If we were to change the filling station to an electric utility in this hypothetical situation, the Smiths are living in the world as we know it today, and as our parents and their parents have known it for the past century. But this may be about to change. Courtesy of the digital revolution, new devices are being introduced into the marketplace that would allow electricity customers to know where their power is going and what they can do to control usage, lower their bills, and also help reduce their carbon footprint.[2]

However, the implementation of these types of devices begs two questions: who is going to install and pay for them, and how much will the devices help lower usage? In this article, we focus on the second question.

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[2] While not the focus of this paper, such changes in customer behavior can also be achieved through indirect feedback, smart-pricing, prepayment, and energy efficiency. Indirect feedback is feedback that has been processed in some way before reaching the energy user, normally via billing [1]. In contrast, direct feedback provides customers with immediate consumption and cost information.

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2. Direct feedback in retail electricity markets and in-home displays

In-Home Displays (IHDs) are drivers of a revolutionary change in the way utilities provide feedback in the electricity market.[3] IHDs provide consumers with direct feedback—real-time energy consumption information both in units of energy and in dollars and cents—and turn a once opaque and static electric bill into a transparent, dynamic, and *controllable* process. Thus, IHDs provide a vehicle for consumers to change their electricity consumption behaviors.

Surprisingly, the effects of various direct feedback systems on consumer behavior have been researched in utility pilot programs and by researchers for quite some time, going back at least four decades. These studies have consistently demonstrated that direct feedback motivates behavior change, resulting in energy savings ranging up to 20 percent. Dr. Sarah Darby [2] of the Environmental Change Institute at the University of Oxford illustrated this point in her book, "Making it Obvious: Designing Feedback into Energy Consumption." She reviewed 38 feedback studies that took place over a period of 25 years, and found 21 studies that consider energy savings associated with direct feedback.[4] Amongst those studies, energy savings ranged from 0 to 20 percent, with 15 of those studies falling in the range of 5–14 percent (The pilot studies reviewed in this paper demonstrate a similar pattern of energy savings associated with the direct feedback from IHDs). Darby [1,2] found that direct feedback was the single most promising form of feedback in curbing energy consumption. Furthermore, she recommended that "metering displays should be provided for each individual household in a form that is accessible, attractive and clear."

Findings in Fischer [3] reinforce Darby's [1,2] conclusions. Fischer [3] reviewed 26 feedback cases from 11 OECD countries. While she did not focus specifically on direct feedback from IHDs, Fischer [3] found that the only feature exclusively to appear "in the best cases (but not all of them) is computerized feedback."

The literature is indicative of the potential that IHDs have to reduce energy consumption. However, who actually benefits from IHDs and any associated drop in consumption? Energy savings benefit both consumers and utilities. Consumers benefit from using less electricity because it directly translates into a lower electricity bill. Environmentally conscious customers derive additional value from cutting back their electricity consumption because it decreases their carbon footprint.

Energy savings at the system level keep the consumption growth under check, and this often means avoiding incremental capacity, transmission, and distribution investments. Utilities further benefit from reduced greenhouse gas emissions as a result of energy savings and, depending on state legislation, may be able contribute energy savings towards renewable portfolio standards progress. With respect to demand response, utilities may find that IHDs, used in conjunction with time-varying rates, augment curtailment of peak demand. For utilities, reduction in peak demand means that expensive peaking units will not need to run as often, and less overall capacity will need to be procured from capacity markets. As we will demonstrate, IHDs and dynamic pricing programs together provide stronger demand response than dynamic pricing can accomplish alone. Thus, IHDs can contribute to energy conservation and demand response, while providing for smoother load profiles and greater electric grid stability.

All of these factors have contributed to the growing interest in IHDs; however, governmental regulation is also nurturing this interest. For example, the European Union requires that energy bills be provided "frequently enough to enable customers to regulate their own energy consumption."[5] While the optimal level of billing frequency is not explicitly defined, IHDs undoubtedly fulfill that obligation on regulated European utilities by providing continuous, real-time feedback on energy consumption to consumers, facilitating their ability to manage their energy consumption.

In light of the current and growing interest in IHDs and the associated consumption impacts, we review several pilot programs that investigate the role of IHD devices on consumers' electricity consumption behaviors. In reviewing the pilots, we address the following considerations: the structure of the pilot program, energy conservation impacts as a result of IHDs, demand response effects of IHDs, and if available, customer opinions regarding the usefulness of IHDs.

Our review suggests that consumers who actively use an IHD can reduce their consumption of electricity by an average of 7 percent when prepayment of electricity is not involved. When consumers both receive IHD feedback and are on an electricity prepayment system, they are able to reduce their consumption by an average of 14 percent. With regard to demand response impacts, we find that the impact of time-varying rates is augmented by direct feedback from IHDs [4].

The pilots reviewed in this paper are listed in Table 1, while results from the individual pilots are summarized in Fig. 1. Appendix 1 provides concise summaries of the major IHD pilot programs, their key features, and results.

Before delving into a review of the individual pilots in this study, we must acknowledge the limitations of our paper. The pilots considered in this study are heterogeneous in terms of pilot structure and design, as well as in other facets, making them difficult to compare directly. The geographic locations and the utilities involved in the pilot studies vary widely, as do the demographics of the consumers involved. Consumers are also subject to various electricity tariffs, and have different price elasticities. Some pilot studies involve randomly selected treatment and control groups, while others do not. Additionally, some pilots lasted for several years, while others lasted only a few months. Other differences between the pilots are also at play. We do not attempt to control for differences in the structures of the pilots. We do, however, provide summary descriptions of each study design where possible. Finally, our paper is limited by the fact that a number of pilots reviewed are not yet concluded; as such, results for these pilots are not currently available.

3. Overview of the pilot programs

3.1. Pilots involving only in-home displays

In this section we review four studies from North America and one from Japan that examine the impact of real-time consumption information from IHDs on consumer behavior.

3.1.1. Canada/Ontario – Hydro One real-time feedback pilot [5]

In the summer of 2004, Hydro One Networks of Ontario, Canada undertook a study to quantify the impact of real-time feedback on

[3] IHDs are also referred to as Real-Time Monitors (RTM).

[4] Refs. [1,2] define direct feedback as feedback that is available on demand, and as learning by looking or paying. The first example of direct feedback she provides is the "direct display", or IHD.

[5] Article 13 of Directive 2006/32/EC of the European Parliament and of the Council of the European Union.

Table 1
Summary of pilots programs investigating the effect of IHDs on consumer behavior.

No.	Pilot	State	Utility	Year
1	Hydro One real-time feedback pilot	Ontario/Canada	Hydro One	2004–2005
2	BC hydro and Newfoundland power pilot	British Columbia and Newfoundland & Labrador/Canada	BC Hydro & Newfoundland power	2005–2007
3	Power cost monitoring pilot program	Massachusetts	National Grid/Nstar/Western Massachusetts electric company	2007
4	SDG&E In-Home Display Program	California	San Diego gas & electric	2007
5	The Kyushu experiment	Japan	Kyushu electric power company	1998
6	SRP M-Power conservation effect study FY04	Arizona	Salt River Project	2004
7	Woodstock Hydro's Pay-As-You-Go	Woodstock, Ontario/Canada	Woodstock Hydro	1989–Present
8	Hydro One time-of-use pilot	Ontario/Canada	Hydro One	2007
9	California information display pilot	California	PG&E/SCE/SDG&E	2004
10	Country energy's home energy efficiency trial	Australia	Country energy	2004–2005
11	TXU energy price guarantee 24 with energy monitor	Texas	TXU energy	2006–present
12	LG&E responsive pricing and smart metering program	Kentucky	Louisville gas & electric	2008–2011

residential electricity consumption in Hydro One's service territory.[6] Over 400 participants were recruited for the study, and their consumption patterns were tracked for a period of over two and a half years. During this time, the treatment period lasted approximately 12 months. Participants were not provided with any rate incentives, and the pilot did not involve enabling technologies.[7] Customers were only provided with the PowerCost Monitor (PCM), a commercially available IHD. Because no rate incentives or enabling technologies were distributed, only the effects of IHD usage on residential consumption of electricity were observed.[8]

3.1.1.1. Impacts. Comparing IHD and control group customers in pre-treatment and treatment periods, real-time feedback from IHDs reduced electricity consumption on average by 6.5 percent across the whole sample. Interestingly, the impact for households with non-electric heating was higher than that of other households, with an average impact of 8.2 percent. The impacts for individual non-electric heating households ranged from 5.1 percent to 16.7 percent. Notably, the observed reductions in electricity consumption were generally sustained for the duration of the study period.

On average, households without electric heating observed a larger conservation impact than the average observed by the whole sample. This may be attributable to electric heating's substantial share of a household's total electricity demand (potentially up to 80 percent in the winter). Because of this high share, consumers are unlikely to be able to detect feedback in response to their non-heating conservation measures; *i.e.*, load from electric heating drowns out feedback signals. Analogously, feedback signals could be drowned out by other household appliances with large electric demands, such as air-conditioning units.

The pilot did not employ or consider time-varying rates, and demand response effects were not studied.

3.1.1.2. Survey results. Customer attitudes towards the PCM were primarily positive. When asked about the usefulness of the monitor in facilitating energy conservation, 63 percent of participants gave the PCM a rating of three or higher on a scale of zero through five. However, in terms of day-to-day usage, only 38.9 percent of participants declared that they referred to the PCM at least once a day. Nevertheless, 65.1 percent of those surveyed stated that they planned on continuing use of the PCM after the pilot concluded.

3.1.2. Canada/British Columbia, Newfoundland and Labrador – BC hydro and Newfoundland power pilot [6]

Over an 18-month period between 2005 and 2007, Customer Energy Solutions Interest Group (CEATI)[9] conducted a pilot similar to the Hydro One real-time feedback pilot. The pilot intended to quantify the effect of real-time feedback, absent any rate or other conservation incentives. The pilot was conducted in British Columbia and Newfoundland and Labrador. Roughly 200 Newfoundland Power and BC Hydro customers participated. The PCM was chosen to serve as the IHD for the pilot.

3.1.2.1. Impacts. Analysis of the results is still underway. However, preliminary results demonstrate an 18 percent average decrease in electricity consumption amongst participants in the Newfoundland Power market and a 2.7 percent average decrease in consumption in the BC Hydro market.

Similar to the Hydro One real-time feedback pilot, this pilot did not employ or consider time-varying rates and as a result, did not study demand response effects. Moreover, customer opinions or survey data are not available since the study has yet to be concluded.

3.1.3. Massachusetts – power cost monitoring pilot program [7]

During the summer and fall of 2007, three large utilities in the state of Massachusetts (National Grid, NSTAR, and Western Massachusetts Electric Company, a subsidiary of Northeast Utilities) conducted studies investigating the cost and benefits of IHDs for residential households. Combined, these utilities distributed 3512 IHDs to customers in their service areas, with NSTAR having the largest deployment of 3103 units.[10] The utilities employed the PCM as the IHD for this pilot (the same brand used by Hydro One, BC Hydro, and Newfoundland Power). The IHDs were distributed to participants during the summer prior to the study at various price points ranging from free of charge to $49.99.

Though the pilot was similar in purpose to the other IHD pilots already reviewed in this section, the evaluation of this pilot's results focused on customer opinions and perceived savings rather than on actual, measured energy savings.

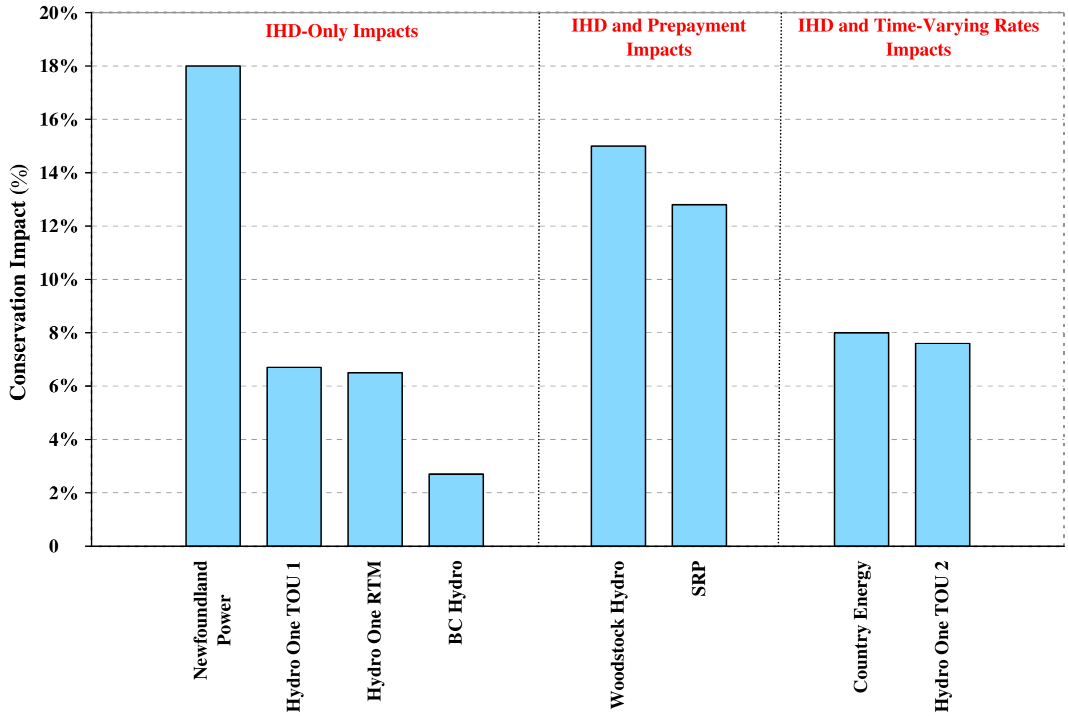
[6] Hydro One service territories include: Barrie, Brampton, Lincoln, Peterborough and Timmins.

[7] Enabling technologies are load control devices, such as smart thermostats and price-response air-conditioning units.

[8] The IHD employed by the study was the PowerCost Monitor ("PCM"), which is commercially available from Blue Line Innovations.

[9] The interest group includes BC Hydro, Newfoundland Power, the National Rural Electric Cooperative Association, and Natural Resources Canada (NRCAN) Office of Energy Efficiency.

[10] National Grid and Western Massachusetts Electric Company circulated 377 and 32 units, respectively.



Notes:

1- Studies without measured conservation impacts as a percent of demand are not illustrated. Enabling technologies in the context of the notes below are defined as load-control devices, such as programmable communicating thermostats and air-conditioning switches. Prepay meters are excluded from this definition.

2- *Newfoundland Power*: BC Hydro and Newfoundland Power Pilot. Enabling technologies and time-varying rates not employed by the pilot. Preliminary impact estimate.

3- *Woodstock Hydro:* Woodstock Hydro's Pay-As-You-Go program. Program based on prepayment for electricity. Enabling technologies and time-varying rates not employed by the pilot.

4-*SRP:* SRP M-Power Conservation Effect Study. Program based on prepayment for electricity. Enabling technologies and time-varying rates not employed by the pilot.

5-*Country Energy:* Country Energy's Home Energy Efficiency Trial. Enabling technologies not employed by the pilot. Time-of-use/critical-peak-pricing rates employed by the pilot and included in measured impact.

6-*Hydro One TOU 2:* Hydro One Time-of-Use Pilot. Enabling technologies and time-of-use pricing considered by pilot; effect of enabling technologies statistically insignificant; effect of time-varying rates included in measured impact.

7- *Hydro One TOU 1:* Hydro One Time-of-Use Pilot. Enabling technologies and time-of-use pricing considered by pilot; effect of enabling technologies statistically insignificant; effect of time-varying rates *not* included in measured impact.

8- *Hydro One RTM:* Hydro One Real-Time Feedback Pilot. Enabling technologies and time-varying rates not employed by the pilot or included in measured impact.

9- *BC Hydro*: BC Hydro and Newfoundland Power Pilot. Enabling technologies or time-varying rates not employed by pilot. Preliminary impact estimate.

Fig. 1. Summary of conservation impacts by pilot.

3.1.3.1. Impacts. Nearly half of the surveyed customers *perceived* bill savings of 5–10 percent. While this may not translate to energy savings of 5–10 percent (due to varying electric rates throughout the consumption period), the perceived bill savings are illustrative of the impacts of IHD feedback on energy consumption.

3.1.3.2. Survey results. Of the surveyed participants, 63 percent indicated they had changed their electricity-use behaviors after using the PCM. Of those that indicated a change in behavior, 41 percent turned off lights more often, 23 percent turned off the TV while it was not in use, 23 percent replaced incandescent bulbs with compact fluorescents, 18 percent turned off computers while they were not in use, and 17 percent unplugged unused battery chargers.

In regard to the usefulness of the data provided by the PCM, 47 percent of surveyed participants who had installed and used the PCM indicated that overall energy use data was the most useful information. In contrast, 37 percent of respondents stated that the most useful information provided was data on energy used by specific appliances.

In terms of bill impacts, among participants who changed their behavior, 60 percent indicated that they had noticed a decrease in their electricity bill.[11] Almost half of those thought they had saved 5–10 percent on their electricity bill.[12]

3.1.4. California – San Diego Gas & Electric in-home display program [8,9]

San Diego Gas & Electric (SDG&E) initiated an IHD pilot in 2007, with 300 participants voluntarily enrolled in the program.[13] Unlike the previous pilots, however, the SDG&E pilot tested the effects of

[11] Twenty-nine percent responded "no" when asked about a decrease in their electricity bill, while 11 percent stated that they did not know.

[12] The next largest respondent group formed 18 percent of the sample size, and stated that they saved between 10 and 15 percent on their energy bill.

[13] SDG&E had proposed an extension to the 2007 IHD pilot for 2008, involving an additional 200 participants, but the pilot was heavily protested by interveners and the extension was withdrawn from consideration by the California Public Utilities Commission, per authors' correspondence with SDG&E.

IHDs as well as conservation phone calls and emails on consumption patterns. The program targeted customers in Southern California who consumed greater than 700 kWh of electricity per month, had central air conditioners, and owned swimming pools. Participants were provided with IHDs (namely the PowerCost Monitor) at no charge. Additionally, customers were notified that they should reduce their energy consumption during peak periods via telephone calls and emails.[14] All participants either already had or were outfitted with interval meters to measure impacts of the IHDs and conservation calls and emails on consumption patterns.

3.1.4.1. Impacts. Preliminary analysis of raw data demonstrates an average conservation effect of 13 percent when compared to their consumption in the previous year, without accounting for weather variations. This impact is the combined effect of both the real-time consumption information from the IHDs and from the conservation phone calls and emails.

Demand response and load-shifting impacts have not been analyzed. Similarly, customer opinion or survey data are not available.

3.1.5. Japan/Fakuoka city – Kyushu experiment

Matsukawa [10] empirically examined and analyzed data regarding the impact of IHDs on consumption gathered during a pilot conducted by The New Energy and Industrial Technology Development Organization and by the Kyushu Electric Power Company during the late summer of 1998. The experiment involved 319 randomly selected households in the Maebaru District of Fakuoka City, Japan, and ran for three months—July through September of 1998, aside from weekends and public holidays. Of the 319 households, 113 were randomly assigned to the group receiving IHDs and 206 were assigned to the control group. Households selected to receive IHDs got the units at no cost, and were also compensated for the cost of electricity to operate the device. All customers were subject to a standard, tiered rate structure.

Unlike many of the other IHD pilots examined in this paper, consumption data was first collected by the utility and then conveyed to the consumer on an hourly basis via a two-way communication link; as such, the pilot involved not only an IHD but also a form of Advanced Metering Infrastructure (AMI).

3.1.5.1. Impacts. The Kyushu experiment found that the reduction in daily consumption due to the IHD (monitor) was statistically significantly and negative. The variable of interest in the study was the "monitor usage" defined by the number of days a participant activated the monitor at least once a day. Matsukawa [10] found that the demand elasticity with respect to the monitor usage was negative and significant, and estimated at −0.015 on average. This implied that an additional day of access to the monitor would reduce daily electricity consumption by 0.053 kWh. This level of energy conservation amounted to 0.3 percent of the average electricity consumption in August.

The study also found that households that used the IHD more frequently had a more elastic demand for electricity than households that used the IHD less frequently. For example, households that used their IHD for more than three days a month had a price elasticity of −0.92 while households that used their IHD only once a month had an elasticity of −0.88. The study did not compare the price elasticities of households in the monitor group to those of the control group.

The study did not examine demand response impacts associated with the monitor usage or formally survey customer opinions.

3.2. Pilots involving in-home displays and electricity prepayment

While several prepay programs exist in North America and abroad,[15] this paper considers two prominent North American studies that involve prepayment of electricity and real-time consumption information similar to that offered by the IHDs examined earlier in this paper.

3.2.1. Arizona – Salt River Project's M-Power prepay program [12]

The Salt River Project (SRP) in the Phoenix metropolitan area initially started as a "Pay-As-You-Go" pilot program that employed an IHD as a means for feedback on consumption and as a platform for the prepayment of electricity. The pilot program commenced in 1993 with 100 participants and then evolved into a formal prepay program for customers with collection problems in 1995. In 1999, SRP introduced a prepay program, "M-Power", that was available to all customers. M-Power is still active today, and is the largest prepay program in North America with 50,000 participants [13,14].

As noted earlier, the M-Power program does not employ IHDs in a conventional manner. M-Power relies on the IHDs in conjunction with a prepay meter and a smart card as a platform for purchasing electricity prior to its use. Essentially, customers must add credit to the smart card at prepay kiosks located throughout the city and at SRP offices. After crediting the smart card, customers must then plug the smart card into their M-Power IHD. The IHD subsequently relays credit to the electric prepay meter located outside of the house and enables consumption of electricity. The electric prepay meter is equipped with an integrated disconnect switch, which halts power consumption when credit runs out.[16]

M-Power customers are not directly subject to any administrative fees for use of the M-Power equipment. They are, however, subject to a one-time deposit of $99 for the equipment. Additionally, the monthly service fee for M-Power customers is a few dollars higher than other residential rate plans.[17]

3.2.1.1. Impacts. Conservation impacts of the M-Power program were studied in 2004 under the "SRP M-Power Conservation Effect Study." The study followed approximately 2600 customers over a period of 12 months. The control group was subject to a standard residential price plan. The results of the study showed substantial conservation impacts as a result of the M-Power prepay system. Relative to the control group, M-Power customers on average saved 12.8 percent annually. Slightly higher energy savings were observed in the summer months (13.8 percent), while slightly lower savings were observed in the winter months (11.1 percent). The impacts of real-time consumption information and of prepayment were not separately identified in the study.

The "SRP M-Power Conservation Effect Study" did not involve time-varying rates, and did not study demand response or load-shifting impacts. Important to note, however, is that SRP is

[14] A small subset of participants did not receive IHDs, but did receive peak-period notifications. This group was set up to measure the impacts of notification on consumer behavior, absent real-time consumption feedback from an IHD.

[15] Globally over 5 million customers use power on a prepay basis, with largest number of prepay users found in the United Kingdom, New Zealand, and South Africa. Prepay electricity programs can also be found at approximately 20 locations throughout North America. See page 2 of Ref. [11].

[16] SRP provides a service, "Friendly Credit," which extends credit and prevents disconnection during nights, weekends, and holidays. The extended credit is reconciled the next time a smart card with energy credit is loaded into the IHD.

[17] The Monthly Service Charge for the SRP Basic Price Plan (E-23) as of April 2009, was $12 per month, while the fee for the M-Power plan (E-24) was $15 per month.

installing smart meters in its service area and plans to offer time-of-use rates to its customers, including those on the M-Power system.

3.2.1.2. Survey results. Customer survey data on the M-Power program indicated that the program was generally well received, with 84 percent of customers reporting being either "very satisfied" or "satisfied." Furthermore, 95 percent of customers felt that they had more control over electricity used under the M-Power program.

3.2.2. Canada/Woodstock, Ontario – Woodstock Hydro's pay-as-you-go [11]

Woodstock Hydro of Canada originally established its "Pay-As-You-Go" electricity prepay system in 1989 as a means of addressing bad debt. As of 2004, 2500 customers were voluntarily enrolled in the program, which accounted for approximately 25 percent of Woodstock Hydro's residential customer base.

Customers are allowed to enroll or leave the prepay program at no charge. They do, however, pay a monthly administration fee that covers the costs of prepay equipment and software. Aside from the monthly administration fee, customers are responsible for purchasing their power prior to using it. The prepay system is very similar to the SRP M-Power system. The system consists of three components: a prepay IHD, smart card, and prepay electric meter. Customers must add credit to the smart card via kiosks located throughout the city. The smart card then plugs into the IHD, which relays credit to the prepay electric meter, and permits consumption of electricity.

Also similar to the SRP M-Power system is the Woodstock Hydro IHD, which displays the following types of information: power remaining (kWh), present rate of uses (dollars or kWh), amount of power used yesterday (dollars), amount of power used last month (dollars), date and amount of last transaction (date and dollars, respectively), current date and time, estimated number of days until card needs replenishment at current use levels, and other data.

3.2.2.1. Impacts. According to Woodstock Hydro, customers on the Pay-As-You-Go program have reduced their consumption on average by about 15 percent. This is relatively consistent with the conservation impact observed in the SRP M-Power Conservation Effect Study (12.8 percent on an annual basis). Similar to the SRP M-Power program, the contribution of IHD usage to the conservation impact is not separately identified from the total effect of both IHD usage and prepayment of electricity.

The program does not involve time-varying rates, and as such, demand response and load-shifting impacts are not available.

3.2.2.2. Survey results. While the Pay-As-You-Go program does not survey customer opinions, an overview provided by Ken Quesnelle [11], Vice-President of Woodstock Hydro, provides another measure of the program's popularity: the rate at which enrollment in the program has grown. According to Quesnelle [11], the program had historically grown at a rate of 3 percent annually as of 2004, and was expected to grow at an even higher rate with the decline of technology costs.

3.3. Pilots involving in-home displays and time-varying rates

In this section we consider five pilots that study the impacts of both IHDs and time-varying rates on electricity consumption. Four of these pilots are North American-based, and of those, two are in progress as of this writing.

Table 2
Hydro One time-of-use pilot conservation impacts [15].

Consumption impacts per Hydro One TOU pilot	
Mechanism	Conservation effect
IHD effect w/TOU rates	−7.60%
TOU only effect	−3.30%
Incremental IHD impact	−4.30%
IHD effect w/o TOU rates	−6.70%

3.3.1. Canada/Ontario – Hydro One time-of-use pilot [15]

In the summer of 2007, Hydro One Networks conducted another pilot program that examined the effects of Time-of-Use (TOU) pricing in conjunction with real-time feedback [15] on consumption by residential, farm, and small general service customers. The pilot took place between May and September 2007, and involved 486 customers split into four groups:

1. 153 customers were subject to TOU rates and were given Real-Time Monitors (RTM) or IHDs;
2. 177 customers were subject to TOU rates and were given a $50 incentive at the end of the program, but they were not given an IHD;
3. 81 customers were given just an IHD and no pricing or participation incentives;
4. 75 were assigned to the control group and, as such, remained on existing rates without TOU pricing and were not given an IHD or any sort of incentive.

The results of the study offered a number of insights on demand response and conservation mechanisms.

3.3.1.1. Impacts. The study concluded that the real-time monitoring, enabled by IHDs and in the absence of pricing incentives, reduced electricity consumption. The impact of IHDs on consumption was measured in two ways: 1) by comparing the energy savings of the group with access to IHDs to the group lacking access to IHDs, and 2) by comparing the energy savings between the group with access to both IHDs and TOU rates with the group that was subject only to TOU rates. Table 2 presents these impacts.

The first measure indicated that IHD usage reduced consumption by 6.7 percent over the pilot period of May through September 2007, relative to a control group without access to an IHD. To calculate the second measure, an incremental approach was followed. The study found that the group with access to an IHD and subject to TOU pricing consumed 7.6 percent less than it did in the same period in the previous year (after adjusting for differences in weather). The study also found that the group subject to TOU pricing alone (in the absence of IHD feedback) consumed only 3.3 percent less than it did in the same period in the previous year (also after adjusting for weather). The difference between the two conservation impact estimates of 4.3 percent provided the incremental conservation effect of IHD usage above the effects of TOU pricing.

In summary, the results of the study revealed that IHDs and TOU rates are both effective tools for conserving electricity. Furthermore, *IHDs perform better in regard to energy conservation than TOU prices*.

The study also assessed the impact of IHDs and TOU on demand response over the May to September 2007 test period. These impacts are presented in Table 3.

The study found that the combination of TOU and IHDs shifted 5.5 percent of load from on-peak to mid-peak and off-peak hours. TOU pricing alone shifted 3.7 percent of load away from on-peak

Table 3
Hydro One time-of-use pilot demand response impacts [15].

Load-shifting per Hydro One TOU pilot	
Mechanism	Demand response effect
All days	
TOU and IHD effect	−5.5%
TOU effect	−3.7%
Incremental IHD impact	−1.8%
Very hot days (>30 °C)	
TOU and IHD effect	−8.5%
TOU effect	−2.9%
Incremental IHD impact	−5.6%

hours, meaning that the "incremental IHD impact on load-shifting"—the difference between the load-shifting effects of TOU in combination with IHDs and TOU alone—was 1.8 percent. Load-shifting during the select, "very hot" days, where the temperature rose above 30 degrees C (86 degree F), was even more pronounced. The combination of TOU rates and IHDs shifted load by 8.5 percent, while TOU rates alone shifted load by 2.9 percent. The "incremental IHD impact on load-shifting" was determined to be 5.6 percent—significantly higher than the average impact across the entire test period.

In summary, IHDs as well as TOU rates, contributed to both energy savings and demand response effects. However, the results suggested that IHD usage has a stronger impact on energy conservation (impact of 4.3–6.7 percent) than on demand response (1.8 percent). Surprising, though, was the average incremental load-shifting impact of IHD usage during "very hot" days (5.6 percent). Nevertheless, the combination of IHD with TOU pricing offered the greatest benefits in terms of both electricity conservation and load-shifting.

3.3.1.2. Survey results. Customer survey data indicated that the IHDs were relatively well received, with 63 percent of those surveyed indicating that real-time monitoring was useful in helping to conserve electricity. However, in regard to installation, 45 percent found installation difficult, both in fitting the IHD's sensor unit around the conventional meter, and in programming TOU rates into the IHD. While many found installation to be difficult, survey participants thought that IHDs would help them save 9 percent on electricity consumption.

3.3.2. California – California information display pilot [16]

The California Information Display Pilot (IDP) was an additional study conducted under the well-known California Statewide Pricing Pilot (SPP). The IDP took place from August to October 2004 and involved customers from both Southern California Edison (SCE) and SDG&E. The objective of the program was to examine the incremental benefits of providing customers with useful information, both through feedback from an IHD and through enhanced billing treatments, while on a critical peak pricing tariff.

Relative to other pilot programs, the California IDP involved few participants: 61 select customers voluntarily agreed to participate in the pilot program [16]. Of the 61 customers, 32 were residential and 29 were commercial customers. Residential customers were selected from a population of customers with average summer energy use in excess of 600 kWh per month. Commercial customers were drawn from the general population, but were screened for a minimum usage threshold. All participants were given an option to have an enabling technology installed free of charge.

The California IDP selected the Energy Orb produced by Ambient Devices as the direct feedback mechanism for the study. Unlike traditional IHDs, the Energy Orb does not present quantitative information. Rather, the Orb provides visual feedback by changing colors in response to price signals. For the pilot, the Orb changed to blue for off-peak hours, green for on-peak hours, flashed red four hours in advance of a critical peak event, and turned solid red for critical peak hours.

In addition to the Orb, the IDP employed enhanced billing treatments in the form of personalized newsletters and internet/email communications. The newsletters provided individual customers with detailed energy use and cost information, including breakdown by off-peak, peak, and critical peak periods. The newsletters also provided a comparison of individual usage to usage by the average household. The website expanded on the newsletter information, and provided interactive tools illustrating the benefits of efficient energy use, tips and "how-to" guides, and energy fun facts.

3.3.2.1. Impacts. The pilot did not explicitly measure the conservation impacts of the Energy Orb. However, a significant portion of surveyed participants noted that use of the Energy Orb had changed their energy consumption behaviors, which led to energy savings (see the Survey Results section). Additionally, the study concluded that information provided by direct feedback increased "the average level of energy savings among residential customers, over and above" the rate incentives employed by the pilot.

With regard to demand response effects, residential customers reduced their demand during both critical peak periods and the corresponding 4-h warning periods leading up to the critical peak periods. This was as a result of feedback from the Energy Orb and enhanced billing treatments, as well as CPP rates. These demand response effects were greater than the demand response effects of CPP rates alone. However, contrary to demand response in the conventional sense, some of the "demand response" measures undertaken by residential customers during critical peak periods were in fact short-term energy conservation measures (*e.g.*, turning off lights and turning down air conditioners) rather than purely load-shifting measures.

3.3.2.2. Survey results. Of the 32 residential customers that participated in the pilot, 23 completed post-treatment surveys. Of those, 70 percent indicated that they had changed their electricity-use behaviors after using the Energy Orb, leading to energy savings. Of 29 commercial customers that participated in the pilot, 26 commercial customers were contacted for a post-treatment survey. Of those, 65 percent indicated that they had changed their electricity-use behaviors leading to energy savings after using the Energy Orb.

Additionally, a general population survey was conducted that included 400 residential and 204 commercial customers.[18] These customers were not part of the pilot effort, and as such, did not receive an Energy Orb and were not subject to dynamic rates. The general survey provided interesting insights on customer behaviors in regard to energy conservation and demand response. The survey indicated that 29 percent of residential customers either strongly agreed or somewhat agreed with the statement that they did not have enough information to shift or reduce their electricity consumption. In comparison, 47 percent of commercial customers either strongly agreed or somewhat agreed with that statement. Nevertheless, when asked about the top three energy users in their household, only 39 percent of residential customers and 35 percent of commercial customers felt confident about their knowledge in

[18] Customers who felt that they could not shift or reduce their electricity use were excluded from further analysis in the survey.

that regard. As such, appliance or device-specific information would seem to be beneficial to customers.

The general survey also questioned respondents about real-time electricity information displays (*i.e.*, IHDs). When asked about whether real-time information on energy would be useful, 59 percent of residential and 50 percent of commercial respondents responded in the affirmative. Furthermore, 63 percent of residential and 52 percent of commercial respondents thought that real-time information would help reduce electricity consumption.

Among those that believed real-time information would be useful, 63 percent of residential and 60 percent of commercial customers thought that IHDs should display what electricity is costing in dollars. Furthermore, 31 percent of residential and 37 percent of commercial customers thought that IHDs should display energy savings from changes in use, to dollars saved. In regard to temporal preferences, 51 percent of residential and 53 percent of commercial customers thought that IHDs should display the amount of electricity/cost so far in the current month. Additionally, roughly 25–30 percent of respondents thought that IHDs should display electricity use and cost projections for the month, amount of electricity use and cost at the current moment, and amount of electricity use and cost so far that day.

3.3.3. Australia/New South Wales – country energy's home energy efficiency trial

Country Energy of Australia [17] tested an IHD in conjunction with critical peak pricing in its "Home Energy Efficiency Trial" (HEET) pilot program, which commenced in December 2004 and ran for 18 months. Two hundred households representing a mix of income, age, familial circumstance, and housing vintage were selected to participate. In addition to the IHD, households had advanced meters installed that were capable of communicating with the IHD. The IHD was equipped to relay real-time electricity consumption information and price figures, as well as peak, off-peak, and critical peak pricing through "Traffic Light" indicators and environmental variables such as greenhouse gas emissions.

3.3.3.1. Impacts. While the impact of real-time consumption information from the IHD was not measured separately, the program as a whole provided energy savings to participants. Median savings over a 12-month period was found to be 8 percent. Furthermore, customers realized an average bill savings of approximately 16 percent.

With respect to the demand response, demand was reduced by approximately 30 percent during critical price events in both the summer and the winter. Again, this impact captures both the impact of time-varying rates and the real-time information.

3.3.3.2. Survey results. Formal survey information was not provided by the study; however, exemplary customer comments were provided. Comments generally demonstrated that the IHD and pilot program were positively received. For example: "One of the most useful aspects was seeing how much standing power was used with nothing running, *i.e.*, standby power of computer and AV devices," and "I have really enjoyed being part of the trial. Our whole household and our friends are all more aware of how much power various appliances use."

3.3.4. Texas – TXU energy SureValue 24 with power monitor plan [9]

In July of 2006, TXU launched a TOU price pilot program that included distribution of IHDs to participants. The initial phase of the pilot included 500 participants. However, as many as 30,000 participants were expected to enroll in the future. As a result of pilot's initial success, TXU Energy decided to offer customers a new rate plan that included an IHD and the TXU Energy Power Monitor, a device similar to the commercially available The Energy Detective ("TED").[19]

No results regarding conservation or demand response impacts from the plan or pilot have yet been published, nor has customer survey data. However, the development of a rate plan based on the pilot structure and IHD involved shows evidence of the program's popularity.

Table 4
Louisville gas & electric responsive pricing pilot and expansion [22,23].

Program	Responsive pricing	Expanded smart metering-DSM component			
	All treatments	Thermo., display & meter	Thermo., load control & meter	IHD & meter	Meter only
Number of participants	150	150	150	100	1450
Treatments					
Meter with card	X	X	X	X	X
Programmable thermostat	X	X	X		
IHDs	X	X		X	
Load control device	X		X		
Responsive pricing rate	X				

3.3.5. Kentucky– Louisville Gas and Electric Co. Responsive pricing and smart metering pilot program

In July of 2007, the Kentucky PSC approved an application by Louisville Gas and Electric (LG&E) to implement a pilot program that involves IHDs in addition to several DSM measures, smart meters, and TOU/CPP pricing. The objective of the pilot is to determine the impacts of dynamic pricing and various DSM measures on electricity demand. The pilot is intended to run for three years, and an evaluation must be filed with the Kentucky PSC by July 1, 2011.

The pilot will effectively be comprised of two presiding study groups: the Responsive Pricing Participants and the Expanded Smart Metering-DSM Component Participants. All participants will receive smart meters, in addition to various combinations of treatments. The first group, the "Responsive Pricing Participants" group, will include 150 customers, of which 100 will be residential and 50 will be commercial customers. They will receive all test treatments, including IHDs, TOU rates, programmable thermostats, and load control devices. The second group, the "Expanded Smart Metering-DSM Component Participants" group, will include approximately 1850 participants. The number of residential versus commercial participants in this group is not explicitly defined. The overall distribution of participant groups and their respective treatments is presented in Table 4.

The smart meters employed by the pilot are actually conventional meters equipped with an electronic card that enables two-way communications between LG&E and the meter. Additionally, the smart meters can communicate with the IHDs and the programmable thermostats employed by the pilot. As such, the IHDs will be able to display pricing periods (*e.g.*, on-peak hours) and critical peak event notifications in addition to usage and cost information. The programmable thermostats will also be responsive to price signals sent by LG&E.

[19] TXU offers the "TXU Energy SureValue 24 with Power Monitor" plan, which includes the TXU Energy Power Monitor IHD.

Appendix 1. In-home display pilot summary table.

Type	Pilot	State	Utility	Year	Number of customers	IHD	Enabling technology	Time-varying rate	Preliminary estimate	Conservation impact	Demand response impact
IHD	Hydro One real-time feedback pilot	Ontario/Canada	Hydro One	2004–2005	382 – test/42 - control	Y	N	N	N	6.5%	N/A
	BC Hydro and Newfoundland power pilot	British Columbia/ Canada	BC Hydro	2005–2007	200 – total in pilot	Y	N	N	Y	2.7%	N/A
		Newfoundland/ Canada	Newfoundland power			Y	N	N	Y	18.0%	N/A
	Power cost monitoring pilot program	Massachusetts	National Grid/Nstar/ Western Massachusetts electric company	2007	3512 – test	Y	N	N	N/A	TBD	N/A
	SDG&E In-home display program	California	San Diego Gas & Electric	2007	300 – test	Y	N	N	Y	13.0%	N/A
	Kyushu experiment	Japan	Kyushu electric power company	1998	113 – test/206 – control	Y	N	N	N	−0.015 demand elasticity w/r to monitor usage	N/A
IHD + prepay	SRP M-Power conservation effect study	Arizona	Salt River Project	2004	2600 – total in pilot	Y	N	N	N	12.8%	N/A
	Woodstock Hydro's Pay-As-You-Go	Woodstock, Ontario/ Canada	Woodstock Hydro	1989–Present	2,500 in 2004	Y	N	N	N	15.0%	N/A
IHD + Time-Varying Rates	Hydro One time-of-use pilot	Ontario/ Canada	Hydro One	2007	81 – test/75 – control	Y	N	N	N	6.7%	1.8% (peak)
					153 – test/75 – control	Y	N	Y (TOU)	N	7.6%	5.5% (peak)
	California Information Display Pilot	California	PG&E/SCE/SDG&E	2004	61	Y	Y	Y (TOU/CPP)	N/A	(not significant)	(not significant)
	Country Energy's Home Energy Efficiency Trial	New South Wales / Australia	Country energy	2004–2005	200 – total in pilot	Y	N	Y (TOU/CPP)	N	8.0%	30% (critical peak)
	TXU Energy Price Guarantee 24 with Energy Monitor	Texas	TXU energy	2006–Present	500 in 2006	Y	N	Y (TOU)	N/A	TBD	TBD
	LG&E responsive pricing and smart metering program	Kentucky	Louisville gas & electric	2008–2011	150 – test/ 1850 – control	Y	Y	Y (TOU/CPP)	N/A	TBD	TBD

Notes: Load-Shifting impacts were measured for various periods, categorized as: peak hours or critical peak hours.
Enabling technologies refer to smart thermostats, regulated water heaters, regulated pool pumps, and other devices programmed to respond to price signals;
Y refers to "yes" and N refers to "no". TBD refers to "to be determined" and N/A refers to "not available";
w/r refers to "with respect".

The pilot is still active, and therefore no impacts or survey results have been published.

3.4. Other notable feedback pilots

In this section we consider other pilots that study the impacts of feedback and information from IHDs, the internet, and other sources, on the demand for energy. Some of these pilots involve prepayment of electricity, while others are focused primarily on impacts of feedback from IHDs.

One of the larger prepay programs internationally is operated by Northern Ireland Electricity (NIE) [18]. The program is quite large, with approximately 20 percent of NIE's customer base, or approximately 125,000 customers, enrolled. Much like customers of other prepay programs [11,12], NIE customers use in-home keypad meters, similar in function to IHDs and the prepay units deployed by SRP M-Power and Woodstock Hydro, to purchase credit for electricity. The combined effect of prepayment and feedback provided by IHDs has led to a reduction of 11 percent in consumption amongst customers with training, and a reduction of 4 percent amongst customers that did not receive training.

Another relatively new prepay program is operated by the Oklahoma Electric Cooperative (OCE). The program originally initiated with a 90-day pilot in August of 2006. The pilot was intended to test the costs and benefits of electricity prepayment and an online feedback system [19,20]. Online feedback on daily consumption patterns was possible courtesy of AMI and smart meters, which were installed throughout the entire customer base prior to the pilot. The prepay program and online consumption monitoring system used in the pilot are now offered as a rate plan through OCE. While feedback is not in real-time, online consumption monitoring offers an interesting alternative to feedback from IHDs. Online monitoring provides information on a daily basis, and includes the following information: current balance (dollars), last energy usage (kWh), last payment (dollars), average daily energy charge (dollars), and last daily energy charge (dollars). According to OCE, the combination of prepaid electricity and online consumption monitoring has led to a 12–13 percent decline in energy use, relative to consumption during the same period a year prior.

Other pilots that have measured the impact of direct feedback on energy consumption have found results similar to those found by the studies reviewed in this paper. A Canadian IHD study published in the 1980s found savings in the range of 4–5 percent [18]. In Norway, customers who received direct feedback regarding their consumption reduced their energy use by about 9 percent [18]. In Victoria, Canada, a small trial involving 50 households served by South East Water demonstrated that real-time feedback provided by IHDs led to a 15 percent decrease in electricity consumption [21]. Finally, in the UK, a small study involving 44 households that received IHDs for cooking showed a reduction in energy use consumption of 15 percent on average [18].

As noted in earlier in this paper, these pilots and their respective results are not directly comparable. However, energy savings trends amongst the studies point strongly to the notion that feedback from IHDs promotes energy conservation.

4. Conclusion

This paper reviews contemporary evidence on the effects of IHDs and other direct feedback on electricity demand. We cover a dozen North American and international pilot programs, some of which are currently underway, and consider the structure of the pilots, the energy conservation and demand response impacts, and overall customer opinions and attitudes towards IHDs and direct feedback on their consumption behaviors.

In regard to conservation impacts, we find that direct feedback provided by IHDs encourages consumers to make more efficient use of energy. In the studies we review, energy savings range from three to 13 percent, with an average of 7 percent (excluding the preliminary findings and the impacts that involved prepayment of electricity). These conservation impacts are consistent with impacts noted in previous literature. When combined with an electricity prepay program, energy savings are about twice that amount. Additional information will be available after the following pilots are concluded and analyzed: the Newfoundland Power and BC Hydro Pilot, the SDG&E IHD Pilot, and the LG&E Responsive Pricing and Smart Metering Pilot.

In regard to demand response impacts, we find that the effect of time-varying rates is augmented by direct feedback from IHDs. However, the evidence supporting this observation is much more limited; only the Hydro One Time-of-Use Pilot and the California Information Display Pilots offer relevant information. Nevertheless, the impact of IHDs in conjunction with demand response mechanisms on load-shifting will be studied by the SDG&E and LG&E Pilots when they conclude, and may also be studied by SRP after they begin to offer TOU rates in conjunction with the M-Power prepay program.

As Darby [2] notes in "Making it Obvious: Designing Feedback into Energy Consumption," it is important to recognize that "feedback is a necessary but not always a sufficient condition for savings and awareness [amongst consumers] [1]." Other factors, in conjunction with feedback from IHDs, play an important role, such as: "condition of housing, personal contact with a trustworthy advisor when needed, and the support from utilities and government which can provide the technical, training and social infrastructure to make learning and change possible." Furthermore, while IHDs do motivate individuals to change their consumption behaviors and save energy, given the time-constrained nature of these pilots, the impacts of IHD have not tested for sustainability. Consumers may initially respond to the direct feedback provided by IHDs, but may lose enthusiasm or interest over time. In defense of the sustainability of conservation impacts, the SRP M-Power Pilot and the Woodstock Hydro Pay-As-You-Go Program have each been around for over ten years and have been successful at curbing electricity consumption all the while. Nevertheless, while both programs utilize IHDs, they are also unlike most other pilots reviewed in this paper because they involve prepayment for electricity, as opposed to conventional, ex-post billing.

One final consideration is whether or not the information itself is useful to consumers. In other words, do IHDs serve simply as reminders to conserve energy, or do consumers actually benefit from the information presented by IHDs? Clearly, this issue is tied to the question of the sustainability of conservation impacts; if consumers actually use and benefit from real-time, quantitative and qualitative information provided by IHDs, then a change in consumer behavior is likely to be preserved. If consumers simply perceive the IHD as a physical reminder to conserve, they may eventually acclimate to its presence and disregard it in the long run—much like an oft-forgotten anniversary marked on the calendar. As is the case with the issue of impact sustainability, this question will be determined over time.

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