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Convenience before coins: Household responses to dual dynamic price signals and energy feedback in Sweden

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ABSTRACT

To enable and cope with an increase of intermittent electricity generation, the power industry and regulators are trying to incentivise users to use electricity at certain times through dynamic pricing and feedback. The effects of such interventions on patterns of electricity use have been extensively studied, yet little is known about how and why householders do or do not respond to such interventions. Using interviews and activity-based diaries, this study provides a qualitative exploration of how and why householders who are subject to a demand-based time-of-use distribution tariff, real-time retail pricing and real-time feedback, do or do not respond to such interventions in their daily lives. We find that the householders have adapted a range of existing practices and have started to engage in new ones that aim to reduce peak demand during peak hours, partly without the support of feedback. Drawing on theories of practice, we challenge common preconceptions about how and why price signals work by demonstrating how the size of the financial incentive that a price signal provides does not have that much influence on householders' willingness to engage in demand response. We argue that price signals work by providing new meanings to practices that use electricity, that feedback can mediate these meanings, and that what matters for householders' willingness to engage in demand response is that the changes they undertake do not cause them any inconvenience by limiting the temporal flexibility of other doings in their daily lives.

1. Introduction

The balance between electricity supply and demand is becoming increasingly difficult to manage as the amount of weather-dependent generation and the electrification of products is increasing while economically viable storage solutions are not readily available at the market just yet [1,2]. To meet these new challenges, regulators are pushing for new market structures to promote new business models, services and technologies that can increase residential electricity users' contribution to the balancing of the grid. Householders are thus increasingly expected to provide the flexibility that the electricity industry is slowly losing.

A common approach to induce demand response (DR) is through dynamic pricing (i.e. time-varying rates or price-based demand response programs), which entails that at least part of the price that users pay for electricity varies over time — the price for the supply of electricity, the distribution of electricity, or both. Although rarely mentioned in the literature on dynamic pricing, the latter scenario implies that users may face more than one dynamic price signal at a time, possibly contrasting and coming from different actors [3–6]. It all depends on the structure of the electricity market in question. In markets that have come far in their liberalisation process and have genuine retail competition (i.e. customer choice) in place, users are free to buy their electricity from any retailer (i.e. supplier or provider) of their choice, while having it delivered by a given monopolistic distribution system operator (DSO). This state of affairs opens up for dynamic pricing at more than one end. For this to happen in practice, retail and distribution costs must be properly separated and communicated transparently [3]. Dynamic retail contracts, whose existence more or less require that DSOs are sufficiently unbundled (i.e. separated from any former supply business), must be available, and a sufficient number of retailers need to exist in a market in order for it to be genuinely competitive [7]. Technical systems such as "smart meters" and reliable communication networks must also be in place to allow for dynamic pricing. Sweden has come a long way in these respects, resulting in that some users are already facing dual dynamic price signals. As we know very little about how users respond to such scenarios and as other countries are expected to follow Sweden's example, the findings of this study should be relevant to any electricity market already being deregulated or moving in that direction.

A number of different dynamic pricing schemes have been developed and tested around the globe, such as time-of-use pricing (TOU or

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TOUP), critical or direct peak pricing (CPP or DPP), critical peak or peak time rebates (CPR or PTR), variable peak pricing (VPP) and real-time pricing (RTP). The main difference between them is how frequently the price varies and how the price variations are communicated (see, for example Darby and McKenna [2] and Albadi and El-Saadany [8] for overviews). Tariffs may consist of several rate components and the time-varying component(s) may be energy and/or demand-based, meaning that the unit of cost is per kWh and/or per kW. Energy-based tariffs are the most commonly used today, although the popularity of tariffs including demand charges is increasing as DSOs strive toward increasing the cost-reflectiveness of tariffs [3,9–11]. In addition, dynamic pricing schemes are often combined with "enabling" or "smart" technologies such as in-home displays (IHDs) or online applications to communicate prices and/or to provide feedback on consumption — all with the aim of increasing DR even further.

The effects, in terms of demand response, of different dynamic pricing schemes (primarily in the form of single energy-based tariffs, with and without enabling technologies) on householders' electricity use in quantitative terms have been studied by many, but the numbers vary widely between studies (see for example [12–15]). Some have argued that the variations can be largely explained by differences in conditions such as the peak to off-peak price ratio and/or access to enabling technologies [14,16,17]. Others have argued that householders' responses to dynamic price signals are more complex, and that we must look beyond the numbers to understand the socio-cultural processes that determine how and why people use energy [18–27]. Doing so will not only help in understanding the variability between studies, but more importantly, to improve the design of future demand-side interventions. We will now provide an overview of important works that have addressed the issue of whether, how and why householders respond to dynamic pricing (with and without feedback) before presenting our study. Given the nature of these research questions, this account primarily covers qualitative studies.

1.1. Studies on how and why householders respond to dynamic pricing

Strengers [19] was one of the first to suggest that dynamic pricing schemes work by creating new "social and cultural meanings" to everyday practices. Her analysis was based on interviews with 23 households (12 with an IHD) that took part in a trial of an energy-based DPP scheme. She concluded that the householders had shifted the majority of practices such as laundering, cooking, vacuuming, clothes drying and ironing to off-peak hours in response to peak price events. However, she found that their motive was rarely financial, but rather a perceived social responsibility to act. This led Strengers to suggest that there seem to be non-financial motivations behind householders' responses to dynamic pricing.

Powells et al. [1] explored the practices of householders during peak hours and the relative flexibility of those practices in response to TOU pricing. Similar to Strengers [19], they found that "*laundry, household chores* [including tumble drying, ironing and vacuum cleaning] *and dish washing practices were performed differently as a result of the introduction of the tariff*", whereas other practices, such as cooking and watching TV were not. Powells et al. [1] concluded that the householders had changed the performance of a number of practices that were not specifically tied to any socially conventional times that would otherwise constrain their temporal flexibility. Although certain practices were identified as being more flexible than others, the authors noted considerable variation between households in how these practices were performed, and thus in how flexible they were. Torriti [28] also highlighted the "timing of energy-related practices" and pointed out that cooking was the least flexible practice. In their investigation of 21 UK households' perceptions of TOU pricing, Murtagh, Gatersleben and Uzzell [21] also found that the timing of cooking practices seemed to be particularly difficult to change due to the temporal rhythm of society. Similar to Strengers [19], they also found that householders expressed non-financial motivations for wanting to respond to dynamic pricing, such as doing something for the general good or because of a feeling of shared responsibility.

Through interviews with eight Danish households involved in a trial of electric vehicles (EVs), an energy-based TOU distribution tariff and an energy-based RTP retail contract, Friis and Haunstrup Christensen [29] explored householders' responses to dynamic pricing. They found that the householders had time-shifted laundry, dishwashing and EV-charging practices in response to the TOU tariff. However, the householders *"found the real-time pricing scheme too complicated and time-consuming to follow"*, leading the authors to conclude that *"[the RTP] scheme did not affect the households' electricity consumption*." [29]. In line with previous studies, the authors found that "*all households also experienced time constraints related to changing the timing of their daily doings*", again suggesting that the temporal rhythm of society limit householders' ability to engage in DR.

Hargreaves, Nye and Burgess [22] provided one of the first analyses of how householders respond to real-time feedback from IHDs through interviews with 15 UK households. Although the householders in their study were not subject to dynamic pricing, the topic was discussed with the householders. In contrast to what Strengers [19] found, the householders said they would "*require significant financial incentives (…) before consider[ing] changing the times of certain practices*" — timings which they had little control over anyway due to the temporal rhythm of society [22]. Given that the householders had reduced their overall electricity consumption in response to feedback from the IHDs, these statements suggest that DR is viewed separately from energy saving, because dynamic pricing introduces temporal restrictions that may conflict with peoples' everyday lives.

Barnicoat and Danson [30] also used IHDs in their study of how elderly use electricity and their willingness and capacity to shift electricity use in time. The participants paid attention to the IHDs which provided hourly feedback on electricity consumption and costs and expressed interest in changing the timing of activities "*to realise savings*" [30], but the IHDs themselves were not sufficient to bring about such changes. Their feelings about dynamic pricing were mixed. Some were willing to adapt to a TOU pricing scheme if it was easy enough, while RTP was perceived as more problematic due to its time requirements and temporal incompatibility with household routines.

1.2. Identified research gaps and the aim of our study

The previous studies have provided a number of insights into how and why householders do or do not (or would or would not) respond to dynamic pricing. Householders who were asked about their willingness to respond to dynamic pricing in theory seemed to be rather unwilling to respond, whereas householders who were subject to dynamic pricing in real life had adapted a number of practices. Hence what householders think they would do in response to dynamic pricing in theory may not reflect what they would actually do if being exposed to it. This calls for further studies on householders who have actually been exposed to dynamic pricing. We must also recognise that the reviewed studies had various ways of capturing the householders' response to dynamic pricing and feedback, which may have contributed to their different results (c.f. Darby et al. [31]). Our review shows that motives for responding to dynamic pricing vary and may not always be related to financial gain, but also to what is percieved as being socially and culturally expected. Furthermore, temporal constraints seem to be an important barrier to DR and some practices seem to be more flexible than others.

A number of questions do however remain unanswered and deserve further attention. Firstly, even though a few studies have been carried out in empirical contexts where both dynamic pricing and feedback has been present, very little has been said about the specific interaction between the two. As feedback is an essential part of dynamic pricing, and both dynamic pricing and feedback may have an individual effect

on householders' electricity use, we believe that it is important to explore how these two elements are taken into consideration by householders who engage in DR. Secondly, none of the studies have examined how householders respond to dual dynamic price signals. As further liberalisation of electricity markets is encouraged worldwide [7,32,33] and as regulators and market actors continuously strive to increase DR, such scenarios may become more common, and since different types of dynamic price signals seem to induce different degrees of response [12–15], it is important to explore how householders deal with having more than one price signal at a time. Thirdly, none of the studies have studied the effects of demand-based tariffs, which are becoming increasingly common as regulators and the industry strive toward more cost-reflective pricing [3,9–11,34]. Since demand-based tariffs aim to reduce individual consumption peaks rather than overall electricity usage, they are more sensitive to how and when electricity is consumed. Therefore, users' responses to such tariffs might differ from their response to energy-based tariffs.

Our study aims to expand and elaborate on the existing knowledge about householders' responses to dynamic pricing and to address these gaps. We do so by providing a qualitative exploration of how and why householders in Sweden, who are subject to a mandatory demand-based TOU distribution tariff, real-time retail pricing and real-time feedback, do or do not consider and respond to such interventions in their daily lives.

1.3. Theoretical lens

As stressed in a number of the above studies, electricity use is an outcome of what people do, and those doings are perceived to be more or less negotiable depending on how they interconnect with the spatio-temporal reality of domestic doings and society at large. These insights and observations fit well with theories of practice in which both social order and individuality are seen to result from "practices" that are "*temporally unfolding and spatially dispersed nexus[es] of doings and sayings*" [35]. Practices as "entities" are actualised and sustained as people or "carriers of practice" perform these doings and sayings [35,36], and they *"emerge, persist and disappear [over time] as links between their defining elements are made and broken.* "[36]. In other words, theories of practice may help to explain why certain doings that require electricity are performed in the way they are with regards to their constituting elements and how they interconnect with other practices in space and time.

As there are a number of different accounts of theories of practice (for overviews, see e.g. [37,38]), there are also a number of different ways in which the elements of practice are defined. In the account of Shove et al. [36], which has been used, e.g. by Stengers [39], to explain how and why people engage in demand response, the elements are defined as (i) materials such as "*objects, infrastructures, tools, hardware and the body itself*", (ii) competences such as "*practical consciousness, cultivated skill (…) or shared understandings of good or appropriate performance in terms of which specific enactments are judged*" and (iii) meanings such as "*social and symbolic significance of participation at any one moment*" [36]. In the context of practices that use electricity, *materials* of relevance may include appliances, enabling technologies and electricity itself; *competences* may include awareness about one's own electricity use, practical knowledge about how to change one's own electricity use and/or shared understandings of how we use electricity; and *meanings* may include meanings associated with electricity itself [39].

As electricity demand is an outcome of social practices, and dynamic pricing seeks to induce a temporal shift in the performances of these practices, it is also important to consider the temporal dynamics of practices [40,41]. In this context, the rhythms of practices, i.e. the "*patterns in the routinised or habituated doing of practices in similar ways at similar times (…) and/or a functional coordination of different practices into connected sequences*" [40] are of particular importance. Dynamic pricing seeks to create moments of "arrhythmia" or "*disturbances to the pre-existing rhythms of performance of practices and the possibility of the emergence of new ones."* [1].

In this study we are inspired by Shove et al.'s [36] account of a theory of practice, and Strengers' [39] application of that account, in analysing and discussing the possible explanations for why householders do or do not alter the timing of the performances of practices that use electricity in response to dynamic price signals and feedback. As it is problematic to observe how householders actually perform electricity-using practices in their everyday lives, we have chosen to base our analysis on the householders' statements about how and why they perform electricity-using practices the way they do given in interviews and diaries. Although some might not agree, Hitchings [42] argues that talking to respondents about how they perform practices is a pragmatic and valid approach.

We now continue with a description of our empirical context and methods (Section 2), empirical observations (Section 3), analysis and discussion (Section 4), and conclusions (Section 5).

2. Empirical context and methods

2.1. The sample, dynamic pricing schemes and research interventions

In contrast to the majority of studies on dynamic pricing, we did not study householders who volunteered to take part in a time-limited dynamic pricing trial. We carried out our study in the distribution area of the DSO *Sala-Heby Energi Elnät AB* in Sweden, where all residential users with a fuse size of 16–25 A (i.e. single-family households) have been subject to a mandatory two-part TOU distribution tariff consisting of a demand charge (SEK/kW, or actually SEK/kWh/h) and a fixed access charge (SEK/year) depending on fuse size since 2009. Previous explorations of the effects of this particular tariff suggest that it has brought about a substantial decrease in peak demand during peak hours which has been sustained over time [43,44]. The area is situated about 120 km from Stockholm and has about 13 500 end users. The users that are subject to the tariff pay for the average of their five highest hourly peaks, during peak hours, every month (Table 1). Consequently, the tariff primarily provides an incentive to avoid hourly peaks, but also to reduce overall electricity use, during peak hours.

Sweden has had a liberalised electricity market since 1996 with retail competition and unbundled DSOs. Consequently, householders pay separately for the distribution and supply of electricity to DSOs and retailers, respectively. Thus, the households in the study area pay separately for the supply of electricity (in addition to the TOU

Table 1
The design and price levels of the two-part TOU distribution tariff applied to users with a fuse size of 16–25 A.

Period	Price (including 25 % VAT)
Peak (7 a.m. – 7 p.m. weekdays except public holidays)	April–October: 40 SEK/kW (4.3 EUR / 5.1 USD)* November–March: 98.5 SEK/kW (10.6 EUR / 12.7 USD)[a]
Off-peak (all other times)	0 SEK/kW

[a] The average exchange rate for 1 SEK during the time the final sample of households participated in the study was ≈ 0.11 EUR or

distribution tariff) to a retailer of their choice. In Sweden, there are about 130 retailers offering a number of different retail contracts that householders can choose from, including energy-based RTP contracts.

However, by 2014, only about 8 600 of the 5.3 million users in Sweden with a fuse size below 63 A had chosen a RTP retail contract [45], where the price of electricity changes hourly to reflect the market price established at the day-ahead market of the Nord Pool power market. The vast majority of users still have a contract where the price per kWh is fixed based on the average monthly (49 percent), yearly (13 percent) or even longer-term (16 percent) price [46]. Thus, there are still very few households that are subject to dynamic pricing at both the distribution and retail level, but the retailer *Sala-Heby Energi AB* which has a high presence in the study area has been proactive in the promotion of RTP retail contracts, which provided a good opportunity to find a sufficient number of households with RTP retail contracts for our study.

The DSO provided us with the contact details of their users and in 2014 we began contacting single-family households, initially via email and if necessary by phone. They were asked whether they wanted to participate in a study in which they would have access to real-time feedback on their electricity consumption and associated costs and thereby help to contribute to an increased understanding of the usefulness of such. 60 households accepted — 19 with RTP retail contracts, 17 with average-monthly-price contracts, 13 with average-annual-price contracts and five with other types of contracts. Each household received a real-time electricity meter that sent consumption data wirelessly to a web-based feedback interface that could be reached from any Internet-connected device. 40 of the 60 households also received an IHD, which could be used for continuous display of the feedback interface anywhere in their home where they had access to Wi-Fi. About 6 months after the last household was up and running, the householders were invited to a meeting where we explained the function and purpose of the TOU distribution tariff and RTP retail contracts, and how they could make use of these dynamic pricing schemes to lower their electricity expenses.

As in most studies on dynamic pricing, our sample of households suffered from “volunteer selection bias” as well as “intervention selection bias”, in that the householders chose to participate in our study, and some to have RTP retail contracts — two biases that are likely to skew findings toward the “positive” end [17,47]. However, instead of seeing these biases as weaknesses, we decided to see them as an opportunity to do a qualitative assessment of a best-case scenario in terms of householders’ willingness and ability to engage in DR; i.e. to study how householders who are particularly interested in the subject and have access to personal guidance respond to dynamic pricing and feedback in their daily lives. With this in mind, it is also worth recognising that single-family homes generally consume more electricity than other housing categories, both in terms of energy (kWh) and power (kW), and therefore have higher electricity expenses. They also have full authority over home investments. Hence, householders living in single-family homes are suitable respondents with regards to our aim.

To make sure that our householders were in fact particularly interested in participating, we asked them a second time whether they wanted to continue to participate for another year after having participated for 10–15 months, while also committing to do as much as they could and found reasonable to adapt their electricity use. They were also offered a one-year subscription to an energy-monitoring service provided by the DSO for free (worth 300 SEK). This resulted in 14 households participating in the project (including one that had not participated earlier) for a comparatively long period of time, thus also allowing us to capture long-term effects. During the remainder of the project three households dropped out — leaving 11 households in the final sample from which we collected our data (Table 2).

We note that the final sample consists of middle-aged and elderly couples. It is not entirely surprising that the average age is high, as younger people may not want, and often cannot afford, to live in a single-family home. However, we still believe that the sample is skewed toward the upper end of the age scale. This in itself may not be a concern with regards to the generalizability of the results, but age is correlated with occupation, and occupation may be of concern. People in Sweden that are 65 years and older are usually retired, possibly meaning that they have more temporal flexibility in their lives. Although this study aims at assessing a best-case scenario, this needs to be kept in mind when interpreting results. To ease interpretation, each quote is followed by the sex, age and household affiliation of each respondent.

2.2. Feedback design

The feedback interface that was provided had been developed together with a smaller group of householders from the same electricity distribution area prior to the study. These householders were identified by the DSO and invited to attend workshops with the aim of developing a real-time feedback interface for electricity use and associated costs. The households were briefed about the TOU distribution tariff and the rationale behind RTP retail contracts to ensure that they had the necessary knowledge. Their preferences regarding the feedback interface were discussed and used as input for a first version of the interface, to which they were given access and tested for some time. The same procedure was repeated until the interface was considered complete and ready to be used in our study. The main page of the final feedback interface is illustrated in Fig. 1.

Except for information on electricity consumption and associated costs in different formats, the householders requested that colours be used to indicate the state of the different parameters in the interface to ease interpretation. Traffic light colour indicators were implemented in the top three boxes on the main page (Fig. 1) as well as in the two bar charts reachable from the bottom menu showing the historical electricity use and the hourly retail price. In the “Right now” box, the colour would go from green to red if the cost for the current hour was in danger of becoming high — either due to a relatively high retail price or because it might become one of the top five peak hours of the month, or both. Similarly, the colour of the “Grid cost” box would go from green to red if the consumption in current hour might become one of the top five peaks of the month. In the “Current electricity price” box, the six cheapest hours during the current day would be indicated in green, the six most expensive hours in red, and the rest in yellow. The same logic applied to the bar chart showing the hourly retail price on the current and coming day. Finally, the traffic light colours were also used to indicate different levels of consumption in the bar chart showing historical usage.

For the sake of our discussion later, it is important to note that the colours of the “Right now” and “Current electricity price” boxes were based on the relative retail price within each day, rather than fixed price levels. This means that a power consumption of 1 kW could be represented by green or red and that a retail price of 1 SEK/kWh could also be represented by green, yellow or red, depending on the retail price in that hour relative to the rest of the day. Worth noting is also the fact that the boxes showing the grid and retail costs at times may display different colours due to the different nature of the two price signals, possibly meaning that they convey contradictory messages to the user about whether it is costly or not to use electricity at that point in time.

2.3. Data collection

Nine months after the households had agreed to remain in the project for another year, the householders in the final sample (Table 2) were asked to fill in personal diaries every day during a week of their choice, and to participate in face-to-face interviews. The diaries were semi-structured around four questions that aimed to capture their views

Table 2
The final sample of households.

Family	Sex and age of household members	Retail contract	Feedback via	Months of participation
1	M 47, F 48, F 17, F 15	RTP	Online portal + IHD	26
2	M 48, F 54, M 15	RTP	Online portal + IHD	24
3	M 57, F 52, M 15	RTP	Online portal + IHD	20
4	M 70, F 70	RTP	Online portal + IHD	20
5	M 73, F 74	RTP	Online portal + IHD	19
6	M 79, F 78	RTP	Online portal	20
7	M 60, F 55	RTP	Online portal	3
8	M 58, F 54, M 20	Yearly fixed	Online portal + IHD	23
9	M 53, F 62	Yearly fixed	Online portal + IHD	20
10	M 66, F 63	Yearly fixed	Online portal + IHD	19
11	M 70, F 69	Yearly fixed	Online portal	21

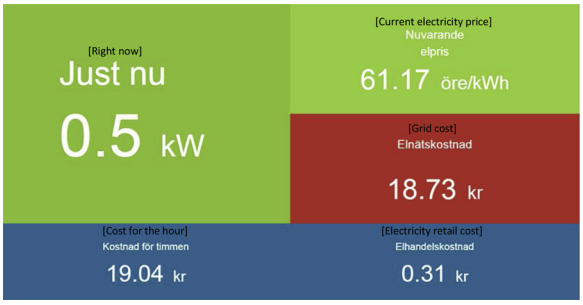

Fig. 1. The default page of the real-time feedback interface at a certain time for a particular household with direct English translations added within square brackets for the purpose of this article. The "Right now" box shows the power consumption in real time. "Current electricity price" shows the current retail price of electricity. “Grid cost” shows the expected cost of distribution given that the household continues to use the same amount of power throughout the hour and “Electricity retail cost" shows the corresponding exptected retail cost. Similarly, “Cost for the hour” shows the total expected cost for both distribution and retail. A menu at the bottom of the interface (not visible here) provided access to further information such as historical consumption on an hourly/daily/monthly/yearly basis and the hourly retail price for the current and coming day.

on what constitutes an electricity-using activity, what materials were involved, if and how they reflected on the price of electricity, and whether they did anything to try to adapt to that price. The householders were asked to not do anything differently that week, as we wanted the diary to reflect their regular everyday lives. In total, 14 householders filled in the diary, representing nine of the eleven households in Table 2.

Semi-structured face-to-face interviews were conducted after the diary week. Similar to Bourgeois et al. [48], we used a number of documents and visualisations during the interviews to guide our questions and facilitate the discussion. These were (i) the diaries, (ii) excerpts from the feedback interface showing graphs of their electricity use each month since the start of their participation in the project, their hourly electricity use and the hourly retail price on each day of the diary week, and (iii) four different non-household-specific scenarios from the main page of the feedback interface, illustrating different consumption and price levels and their associated colours. The documents were used to determine whether the householders had understood and could explain how their doings related to their use of electricity and the hourly retail price, and to investigate how they had used and interpreted the feedback interface.

All household members were asked to participate in the interviews, and in most cases the two adults in each home did. The interviews took 1.5 h on average and revolved around four themes: (i) their perceived impact of their participation in the project on their daily lives; (ii) their perceived reasons to change their electricity use in general; (iii) their perceived impact of the real-time feedback, and (iv) their perceived possibilities to adapt in response to the price signals and the feedback.

Each interview was recorded and transcribed verbatim. Two of the authors of this study participated in the analysis of the transcripts, which entailed reading them through to identify similarities and differences between the householders’ statements regarding how and why they had or had not considered and responded to the price signals and the feedback. The transcripts were read through several times to identify and verify common themes across interviews, as well as to ensure that we did not to miss anything and that the householders’ statements had been interpreted correctly. Finally, the most evident findings with regard to their contribution to our understanding of how, why and why not householders respond to dynamic pricing and feedback were summarised for the preparation of this article.

3. Empirical observations

In this section, we present our empirical observations based on the interviews regarding how and why the householders did or did not respond to the price signals and the feedback in their everyday lives. We begin with a description of what they claim to have done in Section 3.1, followed by a more detailed exposition of what specific aspects of the price signals and the feedback that they considered or did not consider in their doings, in Section 3.2–3.4, with the aim of addressing the identified research gaps. More specifically, Section 3.2 focuses on how the householders considered the different price signals and the interaction between them, Section 3.3 focuses on if and how the feedback facilitated their response to the price signals, and Section 3.4 focuses on how they used, interacted with, perceived and interpreted the feedback itself.

3.1. Adaptions of the performance of everyday practices

We found that all householders (except one whose knowledge about the TOU tariff was uncertain) considered themselves to have made a number of changes in their daily lives. These included recurring temporal adaptions of the performance of both frequent and less frequent practices, new ways of temporally coordinating the use of appliances, as well as one-time changes to the schedules of automated appliances.

The majority of the changes were said to be, or were clearly in response to the TOU distribution tariff. Most commonly, the householders claimed that they regularly shifted the timing of dishwashing and laundry practices from peak to off-peak hours. Other practices such as showering, tumble drying, vacuum cleaning, bubble bathing and sauna bathing were also mentioned as having been shifted from peak to off-peak hours on several occasions. One of the more technically interested householders avoided running the garage heating fan when working in the garage during peak hours and even experimented with manual

operation of the heat pump to see if it was possible to reduce its power consumption during peak hours without causing any major temperature changes in the house.

> "[We would say:] No you can't turn on the dishwasher because it is not 7 p.m. yet"
> (F 54, household 2)

> "We can say: should we turn on the dishwasher? [No] let's wait for half an hour until 7 p.m. That kind of consciousness has grown into our electricity use by now"
> (M 79, household 6)

A few householders also described how they had figured out how to avoid consumption peaks during peak hours by temporally co-ordinating the use of appliances. They had spread the use of appliances across adjacent hours by turning them on in the middle rather than at the beginning of an hour, as well as by avoiding running more than one appliance at the same time. These new ways of coordinating the use of appliances are evidently a result of the demand charge component of the TOU tariff, as it (in contrast to a conventional volumetric charge component) not only incentivises householders to reduce their overall electricity use during peak hours, but also to avoid hourly consumption peaks during peak hours.

> "[Male:] Yes, but is it better if so to say, …if you use a lot of power, …is it better to operate… so to say… from half past twelve to half past one, so that you get [your consumption] on two different hours, or? [Female:] That's right!"
> (M 70 & F 70, household 4)

> "But we know that if one is using the oven and… you don't have to run a lot of other stuff at the same time. So I can warm up the oven one hour and run the hotplate the other hour if I start the oven 10 [minutes] to [the whole hour]. When it has been warmed up it does not use so much energy. Then you can turn on the hotplate the next hour, so that way you spread it [the use] across two hours."
> (M 57, household 3)

Roughly half of the householders who had RTP retail contracts also described how they, in addition to the TOU tariff, took the hourly retail price into account when shifting the timing of the performance of common practices such as dishwashing, laundering and tumble drying, as well as when setting the timer on automated appliances such as dehumidifiers and garage heating fans. Fig. 2 visually summarises all the changes reported by the householders.

3.2. Dealing with dual dynamic price signals

Given that this study is one of the first qualitative studies carried out in a setting where householders are subject to dual dynamic price signals, and that the price signals are different and may sometimes provide contradictory incentives [6], we wanted to know how the householders had dealt with that and considered the price signals in their doings.

Not all householders seemed to have a full understanding of the distinction between the two price signals. However, the majority who did seemed to give the TOU tariff precedence over the RTP, arguing that they had the impression that the TOU-associated costs accounted for most of their bills. Two of the householders that had RTP retail contracts who said that they did not adapt to the RTP also seemed to reason along those lines when arguing for why they chose not to adapt. The reason that they had chosen RTP retail contracts was that they were under the impression that it would be cheaper compared to other types of contracts.

> "You have to run the washing machine sometime. If you run it here [pointing at a relatively low retail price during peak-hours in graph] then you risk to increase the TOU costs. If you run it here [pointing at a relatively high retail price during off-peak hours] then it will cost you two öre [Swedish currency; a wording meaning "very little"] extra [in retail costs] or something like that, but then you avoid getting it [the peak] on the TOU tariff peak hours"
> (M 57, household 3)

> "Since the distribution tariff is based on the five highest values right (?), that is what you want to keep low. Because if you mess up there, it quickly shoots away. And during winter it is expensive as well."
> (M 73, household 5)

> "Yes, you can say that [it is the TOU tariff that we consider firstly rather than the retail price], yes that's the way it is. Because as my wife says it [the TOU tariff] really breaks through [in terms of costs]."
> (M 79, household 6)

3.3. The interaction between dynamic pricing and feedback

Since dynamic pricing and feedback go hand in hand and have been shown to have effects on their own, we wanted to know if and how the feedback had facilitated the householders' responses to the price signals.

We found that all of the householders considered themselves to have learned to adapt to the TOU tariff years before the project started, despite not having access to feedback on the TOU-associated costs of their actions in real time. None of the householders said that the feedback itself had had an additional impact on their adaptions to the TOU tariff. Their claims were supported by the fact that no householder said they had used the feedback on the expected costs for the current hour

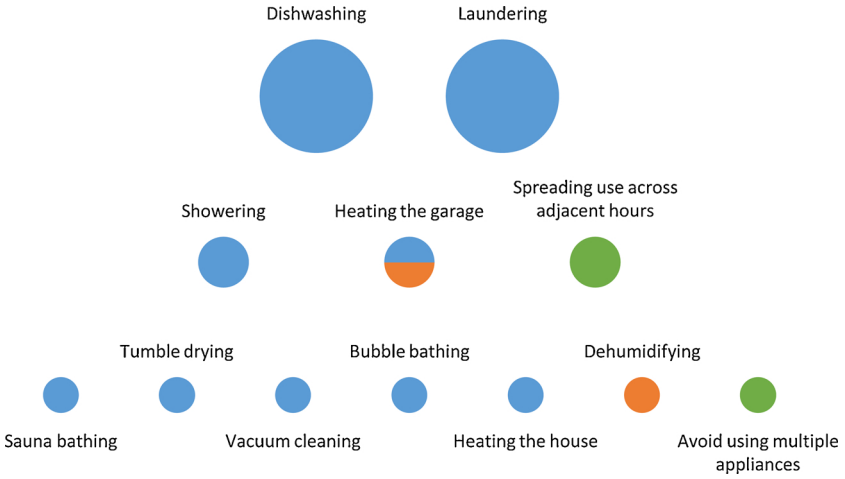

Fig. 2. A summary of all the different changes that the householders mentioned they had done. Temporal adaptions of existing practices are represented in blue, new ways of temporally coordinating the use of appliances in green and one-time changes to the schedules of automated appliances in orange. The more householders that mentioned a particular change, the bigger the bubble.

provided by the feedback interface — neither the expected TOU costs, RTP costs or the total costs. Similar to the findings of Hargreaves et al. [22], the reason for this was that the estimates were perceived as difficult to understand because of their sensitivity to sudden shifts in the current power consumption which sometimes led to seemingly unrealistic numbers.

Even though the householders claimed to have responded to the TOU tariff without the support of feedback, the feedback had played a role for those who also claimed to have adapted to the RTP. One of the households told us how they, in addition to waiting for the TOU off-peak period, waited for the retail price to come down after 7 p.m. before using the dishwasher or washing machine. However, other householders claimed to have found a daily pattern in the retail price which they used to schedule their response instead of following and responding to the actual retail price. The most enthusiastic household always ran their tumble dryer at 4 a.m., arguing that the retail price was usually at its lowest at that time. They also ran a dehumidifier and their winter garage heating during the night to take advantage of the combination of a relatively low retail price and the off-peak hours of the TOU tariff.

> "[Male:] Sometimes it [the boxes in the interface] can be totally red, even though it is after 7 p.m. (…) [Female:] Then we'll wait a bit, because later it is usually green"
> (M 70 & F 70, household 4)

> "Then we found that between about 4–5 a.m. [the electricity price was at its lowest]. And when I realised that it was almost always like that, we just stuck to that… So now we do not look any more, now we just assume that it is then when it is cheapest"
> (M 57, household 3)

> "If you look there [on the hourly electricity price in the feedback interface] for a couple of days, you'll see how it looks…, that it is a kind of pattern, and then it was pretty clear. (…) So based on that, it may not be very interesting to have contact with the electricity meter [the real-time feedback interface] when the patterns are as stable as they are."
> (M 60, household 7)

3.4. The use of feedback

Although the feedback seemed to have facilitated a response to the hourly retail price for a number of householders with RTP retail contracts, most of the reported changes were made in response to the TOU tariff without the use of feedback. Others have made similar observations, such as Murtagh, Gatersleben and Uzzell [49] who observed how householders who engaged in conservation efforts had done so before having access to energy feedback. That being said, all householders in our study still had access to the real-time feedback for a long period of time, which paved the way for an in-depth discussion around how they had used, interacted with, perceived and interpreted the feedback.

In line with what a number of other studies have found [22,23,50], the majority of the householders claimed that the feedback had increased their interest in and general awareness of their electricity consumption. Most householders also said they had used the real-time feedback to explore how much different appliances consumed, and that it had sometimes surprised them to see how much or how little it was. Just as others have observed [21,22], the householders described how their interest in the feedback was greater at the beginning of the project.

As the main parts of the feedback interface that the householders said to have used were colour-coded, we were interested in knowing how they had perceived and potentially made use of that feature. We found that almost all householders had looked for and relied on the colours when assessing the situation, rather than the numerical information provided by the interface. As opposed to absolute numbers on consumption, prices and costs — which many said that they could not relate to — the colours were perceived to be easy to spot and interpret, and quickly gave meaning to the numbers they saw and the situation they were in. Hargreaves et al. [22] also describe how their interviewees showed little interest in absolute numbers and considered them unhelpful in contrast to simple visualisations. This tendency has also been observed in larger surveys, where householders have been asked to rate the usefulness of different feedback features [51], as well as in feedback design studies, where colours in particular have been shown to be perceived as quick and intuitive means of providing information on electricity use [52]. Not only do householders seem to prefer simple visualisations over numbers, but visual prompts as simple as an orb glowing in different colours to represent different price levels have been shown to boost householders' responses to RTP considerably [2].

> "No, it is the colours [that I look for in the box showing the current retail price]. Because the number doesn't tell me much. I do not know what it [the number] is. It is more like: Oh, it is red!"
> (F 48, household 2)

4. Analysis and discussion

Having presented our empirical observations of the householders' doings and their considerations of the price signals and feedback in those doings, we turn now to an analysis and discussion of these observations.

4.1. How do price signals "work"?

As dynamic pricing schemes provide financial incentives to engage in DR, it is natural to presume that any changes made in response to such incentives are made to save money. Indeed, when we asked the householders themselves, saving money was the primary motive for them wanting to change their electricity use, which is in line with the findings of several studies [22,23,49]. Furthermore, the majority of householders who gave the TOU tariff precedence over the RTP said they did so because the TOU-associated costs were higher, suggesting that the size of the potential savings is an important determinant of whether householders respond to dynamic pricing schemes or not. On the surface, these findings seem to resonate well with theories of economic rationality and claims such as that the size of the financial incentive is the main determinant of householders' response to dynamic pricing [14,16,53]. These claims imply that householders simply will not engage in DR to any significant extent if electricity is not expensive enough, as has been claimed to be the case in Sweden [53]. However, a number of our observations lead us to question the importance of financial savings.

The fact that the householders claimed to have adapted to the TOU tariff years before having access to feedback suggests that the magnitude of the savings due to their actions has not mattered to them that much in their everyday decisions. Without feedback, the householders could not possibly have known the TOU-associated cost of their actions, as the hourly costs resulting from a demand-based tariff depend on the size of the peak in the current hour in relation to past peaks during a month. In fact, when we asked the householders directly, none of the householders had any idea about how much money they saved by responding to the price signals. Nevertheless, all householders assumed that they saved some money and said that they thought it was unwise not to adapt if one could.

> "No [we haven't tried to estimate the savings], but it must have [an effect] (…) if it does not affect your life too much then you can do it. Even if you only earn a few [Swedish] krona."
> (F 69, household 11)

> "I know that we earn from it [adapting]. […] I guess it [the financial

saving] is relatively little… The electricity is pretty cheap after all"
(M 57, household 3)

"No [I have not tried to estimate what I would save] I don't think that… it [responding] will render that much [savings] but… it is probably just because it could work [to program the heat pump to switch on and off automatically]"
(M 60, household 7)

Given that dynamic pricing schemes provide financial incentives to engage in DR and that some research suggests that the size of the financial incentive really matters [14,16,53], one may wonder about the significance of our observations. However, we are not the first to have made these kinds of observations. Murtagh, Gatersleben and Uzzell found that financial savings were considered to be an important factor by householders who engaged in energy conservation, but that "*all savings however small were important*" and that they "*appeared to serve a symbolic as well as a monetary function*" [49]. Strengers [19] noted that households in a control group of a DPP trial who received peak event information without any financial incentive to respond reduced their peak event demand by 11–13%. Similarly, in discussing the findings of the largest TOU trial in Ireland, Darby and McKenna noted that "*it appeared as though the main factor affecting customer response was the existence of time-varying prices, rather than the actual figures involved.*" [2].

This leads us to suggest that it is not the actual financial savings that determine whether householders choose to respond to dynamic pricing schemes. So, what is it then? Strengers [39] suggest that price signals can convey new meanings about electricity that have the ability to 'rematerialise' it, turning it something largely intangible to a material element of practice, and thus making it come to matter to practices that use it. In this way, price signals have the power to reconfigure the way in which practices that use electricity are performed and, as our observations suggest, even give rise to new ways of temporally coordinating the performance of practices that use electricity when demand charges are involved.

Strengers suggests that these new meanings may be meanings of "*frugality and finiteness* [that come to life] *without challenging broader meanings of abundance and availability*" [39]. Her suggestion makes sense with regards to householders who claim to be motivated by factors other than financial savings, such as a perceived civic or moral responsibility to act [19,21] or a desire to save energy [49], but does it also apply to householders, such as those in this study, who claim to be motivated by financial savings and willing to make changes as long as they save something? In this context, is it not possible that price signals simply convey meanings of costliness that render the enactment of certain practices, and the use of certain appliances, at certain times as wasteful or unnecessary? If so, is it possible that these meanings are sustained by the fact that the true costs (or gains) are actually unknown to the householders? We cannot say based solely on this study, but we believe that these questions deserve further debate.

Furthermore, as pointed out by Strengers "*prices need to be interpreted to give them meaning, much like language or other symbolic systems which convey social and cultural values as well as economic ones*" [39], which brings us to the role of feedback in conveying meanings about practices that use electricity. In addition to our observation that the householders relied on the colour indicators rather than the numerical information provided by the feedback interface, we also observed that the colours had pre-inscribed symbolic meanings for the householders that seemed to have an effect on their perception and interpretation of prices, costs and consumption levels. To them, the colour green meant that everything was fine, whereas the colour red signalled that something undesirable was going on that required their attention, which is in line with what others have found [20,31,52].

"I probably look mostly at the colour. Because green means OK. That's how I think."
(F 48, household 1)

"There [pointing at a red-coloured box showing current retail electricity price] you can see that you shouldn't turn on things. The price is extra high at the moment"
(M 57, household 3)

"Kronor and öre [Swedish currency; roughly meaning "euros and cents"], I don't think about that too much. When they display is green then it is OK, something like that"
(M 53, household 9)

Even though the colours could have been programmed to mean many different things, none of the householders had seriously reflected on how the colours corresponded to the numbers; they simply trusted their "correctness". A red-coloured number, irrespective of its size, was interpreted as "bad" (i.e. high). This means that a red-coloured price level of, e.g. 0.5 SEK/kWh or a consumption level of e.g. 1 kW, could be interpreted as being high even though the numbers themselves may be low in absolute terms or in comparison to normal levels over longer periods of time. This illustrates how feedback may act not only as a passive conveyer of information, but also as an active ingredient in the crafting of meanings associated with practices that use electricity — both by mediating the meanings provided by price signals and by "translating" intangible numbers describing consumption, prices and costs into something meaningful.

4.2. What determines whether and how far householders are willing to adapt?

Given that price signals "work" through the meanings they convey (both with and without feedback) about practices that use electricity, rather than through the actual financial incentive they provide, what determines the level to which householders are willing to adapt?

In talking to the householders about which changes they considered themselves to have made and why, they said they were willing to make any change as long as it did not cause them any inconvenience in their daily lives. If we understand convenience as being "*associated with the capacity to shift, juggle and reorder episodes and events*" in time as suggested by Shove [54], this can be understood as a willingness to change as long as it does not limit the temporal flexibility of other doings in their everyday lives.

Dishwashing and doing the laundry were practices that the householders mentioned as being easy to shift in time without interfering too much with the temporal rhythm of their lives. Several others have also found that householders seem willing to shift these particular practices in time [1,19,30]. However, Friis and Haunstrup Christensen concluded that "*households generally experienced the extra doings and loss of control* [associated with time-shifting of dishwashing and laundering] *as stressful and inconvenient, particularly during weekdays*" [30]. Apart from the findings of Higginson, Thomson and Bhamra [55], previous research [1,21] also support our finding that householders are unwilling to change the timing of cooking and eating practices. For householders who work and/or have children, cooking and eating practices are strongly connected to the temporal organisation of other practices such as going to work, taking children to school, doing homework, watching television, etc. [56]. However, even the householders who were retired did not seem willing to shift the timing of their meals, suggesting that the apparent inflexibility of cooking and eating practices has to do with bodily needs as well as temporality.

"It [using the dishwasher on off-peak hours] is so simple that you do not even have to think about it"
(M 60, household 7)

"It must not get inconvenient, and I mean to eat […] having regular meals is important."
(M 73, household 5)

"No, it [the adaptions] should not go to extremes, we're supposed to be able live"
(F 78, household 6)

When discussing the diary week with the householders, they all felt that they had done everything in their power to adapt without causing inconvenience, and said that no further adaptions than the ones they had already made would have been possible. This could help to explain why the householders did not consider the introduction of the real-time feedback to have had any additional impact on their adaptions to the TOU tariff, i.e. they had already done everything they were willing and able to do without causing inconvenience.

"…you cannot ONLY save electricity, you have to put it in relation to wanting a worthy life"
(M 66, household 10)

"When we were done with that [the adaptions we had already made] we were satisfied, so after that we haven't, or at least I haven't cared."
(M 57, household 3)

"I don't think that you can get any lower [in electricity use] than that. Then you will change your life to the worse in some way."
(M 66, household 10)

So how is it then that the feedback seemed to facilitate a response to the RTP if the householders had already done everything they were willing and/or able to do? Well, the fact is that the real-time feedback did not lead to any further adaptions than those already made in response to the TOU tariff, but rather it led to that the householders took the RTP into account as well. That is, not only did they shift the performances of practices from peak to off-peak hours, but they also shifted the performances to times of low retail prices. This illustrates how the introduction of a second dynamic price signal may affect the timing of the performance of practices that are already temporally negotiated, while the limit of which practices that are considered negotiable with regard to their impact on convenience remain the same.

The importance of convenience was not only evident with regards to how far the householders were willing to adapt to the price signals, but also to the way in which the householders used the feedback interface. The fact that a number of householders with RTP had identified a recurring retail price pattern that they used as a rule of thumb when timing the performance of certain practices suggests that the householders valued predictability before correctness, in that it allowed them to respond to the RTP without causing inconvenience. This new mental retail price signal that they had created was not only predictable, but it also aligned the temporal demands that each price signal put on the householders, thus allowing them to adapt to both signals simultaneously without having to bother about their hourly interaction.

These observations also provide clues that could help to explain the general decrease of the householders' interest in the feedback over time. Similar to Hargreaves et al. [22], we suggest that the householders quickly learned what they needed to know in order to make the changes they could and were willing to make without causing any inconvenience. This naturally eliminated the need for further feedback, even though they were subject to two different dynamic price signals. Consistent with this suggestion, almost none of the original 60 householders that accepted to take part in the study wanted to keep the real-time feedback for a discounted price after the study. As such, we feel inclined to question the claim of Buchanan, Russo and Anderson that "*If feedback is to maintain its effectiveness over time* (…) *consumers* [must] *continue to engage with* [it]" [23].

Furthermore, even though the householders reported that they had reacted strongly to the colours provided by the feedback interface in real time, their reaction did not seem to translate into immediate action. When confronted with red colours in real time, their immediate reaction was to try to understand what was going on, but once they had found a satisfying explanation (which they most often did), they did not perform an immediate action to try to lower their electricity use in response, because most often, doing so would cause them inconvenience. A few householders said that they had considered doing things differently the next time when having been confronted with red colours, but only if it would not cause them inconvenience.

"When we have a red power consumption, we are often doing something. Then we're busy. […] If you're cooking food it [the feedback interface] might display something else [as in red], but then we aren't looking at this [the feedback interface]"
(M 57, household 3)

"When you see that the display shines red you understand that – OK, this was a bit high, high consumption here and this is also expensive, so next time we won't do it like this, we'll do it like that instead. If there is a possibility to change [what we do], it is not always possible, but IF it is."
(F 54, household 2)

"[Male:] No [we don't turn things off] because it happens sometimes that it gets like this [red] during daytime when you're cooking or [using the] oven, stuff like that. Then it can become like this [pointing at red-coloured box], that all is red. It happens. [Female:] It happens. [Male:] And then you get a bit frightened, because that's not how you want it, but you can't do much about it. [Female:] You get a bit angry, but you continue [to do what you're doing] anyway"
(M 70 & F 70, household 4)

To summarise, many of our observations suggest that the impact on convenience is at least as important as the size of the financial incentive for determining how far householders are willing to go in response to dynamic pricing and real-time feedback. Before concluding, we want to raise a few issues regarding why certain practices may be portrayed as being "more flexible" often than others. Firstly, in thinking about which performances of practices householders are willing to shift in time and why, we must keep in mind that different practices are more or less common across households to start with. Practices that a majority of householders in a given study claim to shift in time are not necessarily practices that are particularly easy to shift in time in comparison to others. They might simply be more common than other practices that exhibit the same kind of temporal flexibility. For example, in Sweden, all single-family homes have a washing machine, and most also have a dishwasher, meaning that doing the laundry and the dishes are practices that are carried out in most households. However, not all households have tumble dryers, garage heaters, bubble baths or saunas, etc. This means that practices that are associated with these less common appliances are naturally less likely to pop up as practices that householders report to have adapted in response to demand-side interventions.

Furthermore, we noted that the practices that the householders said they had adapted were practices associated with appliances that use a lot of power (wattage). Some of these practices might also be particularly easy to shift in time, but since other practices that we believe hold a similar degree of temporal flexibility are missing from the list (e.g. charging of mobile devices), we believe that there is more to this than mere coincidence. We find it likely that the householders' knowledge (i.e. "competences") of how much power different appliances use has an influence on which practices they consider being relevant to change when given an incentive to do so. This may not seem as controversial, but it has consequences for the discussion on the temporal flexibility of the performance of practices, because it means that practices that hold similar temporal flexibility may be considered to be quite different in terms of their negotiability, depending on how much power and/or energy (i.e. kWh) those practices are perceived to use. As competences are shaped by the social and cultural context wherein householders live, their education, etc., paying attention to this might help to explain differences between studies carried out in different socio-cultural

contexts with regards to what practices householders are willing to adapt the performance of in response to demand-side interventions. This also highlights the potential role of feedback in influencing householders' response to dynamic pricing in more ways than we have discussed here, as it seems likely that feedback may be involved in the crafting of householders' competencies.

5. Conclusions

This study aimed at increasing our knowledge about how and why householders do or do not respond to different dynamic price signals and real-time feedback. To explore just how far householders may be willing and/or able to go, we chose to study householders living in single-family homes who were subject to dynamic pricing and showed a particular interest in taking part in a research project where they would receive feedback on their electricity use and associated costs. As it turned out, the final sample of householders consisted mainly of middle-aged and elderly couples. Whether this is a sign of this particular group of citizens being more interested in taking part in research projects or more motivated to engage in demand response is unknown. Hence, readers should keep the characteristics of the sample in mind when assessing the generalizability of the results. Although exploring these aspects has not been a part of the purpose our study, we recognise that householders of different gender may respond differently to dynamic price signals and feedback, e.g. due to how different household chores are divided between individuals, and we therefore encourage readers to keep this in mind as well.

As part of fulfilling the overall aim, this study set out to explore three research gaps, one being the interaction between dynamic pricing and feedback. Our observations suggest that for demand response purposes, feedback has a limited role to play, and that is mainly in the communication of hourly retail prices, in the short run. The householders had not used the feedback to respond to the demand-based TOU distribution tariff. They had already understood the concept of peak and off-peak hours and made the changes they were willing and able to make without causing themselves any inconvenience. The householders with RTP retail contracts initially used the feedback, but most of them lost their interest in it once they had learnt when the retail price was usually high and how its recurring daily pattern interacted with the TOU tariff's peak and off-peak hours. In the long run, this meant that householders with RTP relied on their understanding of how the retail price usually varied over a day when engaging in demand response, rather than the actual retail price on a daily basis. Our observations of how the householders had interpreted the feedback interface do however suggest that simple design elements, such as colours, can change a householder's perception of what constitutes a high price and/or a high power consumption.

Another research gap that we wanted to explore was how householders respond to dual dynamic price signals — in this case a combination of a demand-based TOU distribution price signal and a RTP retail signal. When confronted with both price signals, householders tended to give precedence to the TOU signal, and as explained above, to translate the hourly retail price into a "TOU retail price signal". This mentally constructed price signal was not only convenient and predictable in comparison to the hourly retail price, but it helped the householders to align the temporal demands that the two price signals put on them, allowing them to respond to both signals simultaneously without having to take their hourly interaction into account.

A question related to the third research gap that we wanted to explore was whether householders' response to demand-based tariffs differ from their response to conventional energy-based tariffs as they incentivize different usage patterns; cutting hourly peaks versus lowering overall electricity usage. Most householders did not respond differently, but limited their efforts to recurring temporal shifts of the performance of practices and made one-time changes to the schedules of automated appliances to lower their overall electricity use during peak hours. A limited few of the householders did however report that they had also engaged in temporal coordination of their use of appliances to cut their hourly peak demand during peak hours. This observation adds to the limited literature on how householders' respond to demand-based tariffs in comparison to conventional energy-based tariffs.

We naturally presume that any changes that householders make in response to price signals are made to save money, yet we observed that the householders' knowledge about how much money they were actually saving was non-existent. Drawing on theories of practice and previous research, we hypothesize that dynamic price signals "work" by bringing new meanings to practices that use electricity which encourage householders to shift the performance of those practices in time. In line with observations made in a number of previous studies, we suggest that the mere existence of a price signal may therefore be enough to induce demand response, and that the degree to which householders respond may largely be determined by the degree to which responding causes inconvenience, rather than only by the amount of money they are saving.

In summary, our findings have a number of possible policy implications. Firstly, as the success of a price-based demand response program may not only depend on the size of the financial incentive it provides, it might be more effective to inform users of how they can adapt by changing the timing of the performance of certain practices and of the use of appliances, rather than providing them with details about tariff structures and cost calculation examples. Secondly, if price signals get too complex and/or too demanding to follow and respond to, individually or together, householders might either ignore them or simplify them to the extent that they no longer provide the incentive that was intended. If the aim is to reduce overall usage during hours of peak demand and/or peak prices, TOU tariffs might therefore be more effective than highly dynamic pricing schemes such as RTP in getting the message across. Separate billing of distribution and retail costs may also entail that the financial incentive to respond is perceived as smaller than it is. This may be another reason to avoid combining different dynamic price signals. Thirdly, with demand-based tariffs, users may engage in "time-coordinating practices" during peak hours that lower their costs, but not necessarily their strain on the grid, as they might simply be shifting the timing rather than the magnitude of their peaks. Adding a volumetric charge component to a TOU tariff and/or shortening the billing time interval may help to alleviate such unintended effects. Lastly, real-time feedback seems to play a limited role in facilitating householders' response to dynamic pricing in the long run. It might be more effective to spend money on educating users on how to respond to price signals, rather than on complex feedback systems. The role of feedback may however change as users start to produce and/or store their own electricity as such developments will change the conditions under which real-time feedback and dynamic pricing operate today. In which ways and to what extent the requirements and preferences of consumers and prosumers might change in response are research questions that need to be further explored.

Declarations of interest

None.

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