



Turning green: Agent-based modeling of the adoption of dynamic electricity tariffs

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HIGHLIGHTS

- We propose an agent-based model to study the adoption of dynamic electricity tariffs.
- The decision to change the tariff is based on the unanimity of τ past opinions.
- The model explains why the empirically observed intention–behavior gap exists.
- The adoption of dynamic tariffs is impossible due to the high level of indifference in today's societies.
- Reducing the indifference level or decreasing the decision time can result in narrowing the gap.

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ABSTRACT

Using an agent-based modeling approach we study the temporal dynamics of consumer opinions regarding switching to dynamic electricity tariffs and the actual decisions to switch. We assume that the decision to switch is based on the unanimity of τ past opinions. The resulting model offers a hypothetical, yet plausible explanation of why there is such a big discrepancy between consumer opinions, as measured by market surveys, and the actual participation in pilot programs and the adoption of dynamic tariffs. We argue that due to the high indifference level in today's retail electricity markets, customer opinions are very unstable and change frequently. The conducted simulation study shows that reducing the indifference level can result in narrowing the intention–behavior gap. A similar effect can be achieved by decreasing the decision time that a consumer takes to make a decision.

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1. Introduction

Today's energy markets face many challenges. Among them the imbalance between the growing demand for electricity on one hand and the depleting supply of fuels on the other. On top of that, the power system faces an increasing presence of distributed renewable generation and has to cope with the old and often inefficient technical infrastructure and the changing expectations of the societies (Allcott, 2011; EC, 2007, 2012). Demand side management and demand response tools (DSM/DR) nowadays attract the

attention of the main market players: politicians, system operators, electricity retailers and consumers. A wide range of DSM/DR instruments is being considered, starting from education (encouraging efficient usage of energy), through time-based pricing (time-of-use rates, critical peak pricing, real-time pricing) to incentive-based DR (direct load control, emergency demand response programs, capacity market programs), see e.g. Darby and McKenna (2012), Faruqi and Sergici (2010), Gerpott and Mahmudova (2010) and Strbac (2008).

From this plenitude of DSM/DR tools we focus in this paper on time-based pricing, often referred to as *dynamic pricing*. The main difference between dynamic pricing and flat, conventional tariffs is the dependence of the price consumers pay for electricity on the actual balance between supply and demand in the wholesale market. With such a tariff the consumer may experience several changes in price levels during the day due to the fluctuations of the exchange established spot price (Faruqi and George, 2005;

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Thorsens et al., 2012). Dynamic tariffs have been invented to flatten the curve and to shift the demand from on-peak to off-peak hours. On one hand, the shift of load implies a change in consumer habits and daily routines. On the other, it may be also connected with the reduction of the overall energy consumption. Dynamic tariffs are often supported by the so-called enabling technologies, like smart meters, in-home displays, smart plugs, smart appliances and home area networks (FORSA, 2010; Gerpott and Paukert, 2013; Jongejan et al., 2010; Paetz et al., 2012; Star et al., 2010). These technologies make the control of the energy consumption easier for the customers. In particular, the appliances are automatically turned on or off, according to the changing electricity price and time ranges.

Dynamic tariffs can bring benefits to consumers (potential savings, satisfaction to be ecological) and to electricity retailers and distribution system operators (lower investment and operational costs). However, as many pilot programs and surveys conducted in the recent years have shown, it is quite difficult to get people really involved and to convince them to actually switch to dynamic tariffs (Allcott, 2011; Duetschke and Paetz, 2013; OFGEM, 2011; Ozaki, 2011; Star et al., 2010). This situation is due, in the first place, to the general indifference of residential consumers with regard to energy, and electricity tariffs in particular. Secondly, the savings that are attainable in many cases are not impressive enough to encourage more people to enroll in the dynamic pricing programs. Finally, switching to the new tariff is often connected with some discomfort, because of the need to reschedule energy consumption according to price signals from the wholesale power market (ATKearney, 2012; Faruqui and Sergici, 2010; Thorsens et al., 2012). For these reasons large fluctuations in consumer opinions about electricity tariffs can be observed: one day they are in favor and the next they are against due to their general indifferent attitude to the pricing programs (they do not care, they are disengaged, they do not find it interesting and worth their attention). Consumer opinions and final decisions are also influenced by the social impact of their neighbors (people prefer to have the same opinion as the majority of the group) and the external influence or field (e.g. advertising of new pricing programs by some electricity retailers). As a result the intentions to reduce energy consumption do not always translate into decisions or actions. The literature calls this discrepancy between opinions and decisions the *intention-behavior gap* (Godin et al., 2005; Fennis et al., 2011; Ozaki, 2011; Sheeran, 2002), the *value-action gap* (Gadenne et al., 2011), the *KAP-gap* (*knowledge-attitudes-practice gap*; Rogers, 2003), the *attitude-behavior gap* or the *belief-behavior gap* (Kollmuss and Agyeman, 2002).

Empirical studies of consumer behavior are time consuming, costly and generally of limited scope. It is hard to imagine a survey involving a few million retail customers, conducted every day for a period of, say, 2 years. Agent-based or artificial society models, on the other hand, allow for multi-run experiments conducted under different market conditions and for different agent specifications. Agent-based simulations have been also applied to model the demand side of electricity markets. In most papers, however, the focus has been only on opinions (like in Kowalska-Pyzalska et al., 2014) or no distinction between opinions and decisions has been made at the modeling level. For instance, in the model of Zhang and Nuttall (2011), when facing a number of options, the one for which a given residential electricity consumer has the greatest intention is his or her preferred option, i.e. it is his or her final decision on which energy supplier to use and whether to choose a smart meter or not. Yet, there are papers that pay attention to the difference between the *willingness-to-pay* (WTP) and the actual adoption, but consider the market of green, renewable energy, not dynamic tariffs (Diaz-Rainey and Tzavara, 2012; Ozaki, 2011).

In this study we focus on the difference between consumer opinions (or attitudes) and decisions (or behaviors) regarding switching to dynamic tariffs. Using an agent-based modeling approach, we

show how personal attributes, like conformity and indifference, on one hand, and advertising, mass-media education programs and financial incentives, on the other, may impact the decision making process of individual electricity consumers.

The paper is structured as follows. In Section 2 we review the results of pilot programs that have been run recently in the U.S. and in Europe and whose aim was to evaluate consumer attitudes towards particular demand response tools. In Section 3 we first discuss the innovation diffusion phenomenon as a five-stage process, which includes, among others, the persuasion stage (forming and attitude or opinion) and the decision stage (adoption). Next, we focus on the behavioral aspects of the transition from opinions to decisions, in particular, in the context of energy conservation. In Section 4 we concentrate on the opinion-to-decision transition algorithm we use in this study and briefly review the underlying agent-based model of opinion formation, originally introduced in Przybyła et al. (2014) and adopted to the case of electricity consumers in Kowalska-Pyzalska et al. (2014). In Section 5 we present the results of our simulation study. Finally, in Section 6 we wrap up the results and discuss policy implications.

2. Pilot programs

The rapidly increasing number of distributed generators, like renewable energy sources (RES) or cogeneration, has recently led to a change in the philosophy of power system architecture and operation and the introduction of *smart grids*. The latter idea is closely related to DSM/DR tools, which have been known for years, but nowadays attract much more attention. At the same time the EU long-term strategy and the climate policy call for an increase of energy efficiency, an increase of market penetration by RES and a reduction of CO₂ emissions in the coming years. Among EU regulations, directive 2012/27/EC paves the way for widespread introduction of smart meters that would provide feedback to private households on their energy consumption and information about energy efficiency (EC, 2012).

In order to achieve the ambitious goals set by the EU, a durable change in consumer attitudes and behavior is needed. Without consumer willingness to adopt to dynamic tariffs and without their effort to reduce energy consumption, the efficiency of energy usage will not increase significantly. In the last 10 years a number of pilot programs and surveys in the U.S. and Europe were conducted in order to measure and evaluate the reduction of peak demand and energy conservation at the consumption level (Ehrhardt-Martinez et al., 2010; Faruqui and Sergici, 2010; Jongejan et al., 2010; Sopha et al., 2011; Star et al., 2010). Many of those experiments were run in an attempt to understand consumers' responsiveness to variation in retail electricity prices (Allcott, 2011; ATKearney, 2012; Faruqui and George, 2005; Grans et al., 2013; Ozaki, 2011; Thorsens et al., 2012).

Switching from a traditional tariff to a dynamic one has been found to reduce peak demand up to 44%, especially when accompanied by enabling technologies (Ehrhardt-Martinez et al., 2010). However, the cost of the enabling technologies is currently higher than potential savings (Gerpott and Paukert, 2013; Jongejan et al., 2010; Paetz et al., 2012). The pilot programs have also revealed another unwanted feature. Namely, only a small fraction of the program participants decides to sign up for dynamic tariffs after the pilot programs are ended. For instance, the *AIU Power Smart Pricing Program* in Illinois has shown that only 18% of customers, where the pilot program was run, were aware of it. Then, only 10% of them understood the program and only 5% were interested in the program. In the end, under 1% of customers enrolled in the program (Star et al., 2010). Similar survey results have been obtained in other pilot programs in North America and Western Europe, in countries where the societies are rather aware

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