

Simulation for policy assessment of rationally-bounded energy-use, in competitive markets

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ABSTRACT

The recent liberalisation of energy markets provides a challenge for understanding the decision-making processes of the agents involved. In this new environment, it is of particular interest to investigate consumers' decisions with respect to energy efficiency for the purpose of assessing government policy and traders' strategy intents.

The Neo-classical methodologies reported in the literature generally make, strong and not evident, assumptions with respect to the decision-making processes of end-users, including: complete information, full rationality and lack of risk-perception. In this paper, the concept of bounded rationality (Simon, 1979) is incorporated, seeking alternative grounds to the traditional methodologies.

Against this background, we examine different sets of assumptions based on the concept of "rationally-bounded energy-use" and propose policies that may reduce some of the apparent market failures. However, both this claim, as well as the proposed simulation models that intend to account for bounded rationality (BR) need to be clearly justified. Here, we do this by indicating, explicitly and implicitly, how BR operates and what policies and strategies might be appropriate to remove some of the consumers' barriers when confronting decisions. The simulation models presented in this paper incorporate consumers' behaviour and alternative policies to assess their likely impact on society. Examples related to the penetration of fuels and lighting appliances are provided, to illustrate the approach.

Key words: Consumers' choice, energy efficiency, industrial organisations, bounded rationality, institutional economics, simulation.

1 INTRODUCTION

In the forty years, since the end of World War II, the central planning paradigm in the electricity industry has been exhausted. By the late 80s, there was a world-wide trend to disbelief in the effectiveness of state owned monopolies being in charge of public services. This has given way to important reforms initially in Chile, the United Kingdom and Norway, and a few years later in other European and American countries and states, as well as in Australia and New Zealand. The most common changes that have been implemented (Armstrong, *et al.* 1994) are:

- Elimination of vertical integration, unbundling the transmission, distribution and generation businesses.
- Introduction of competition, where possible, in the electricity industry.
- Promotion of private investment and the privatisation of state owned companies.
- Promotion of efficiency and innovation in the electricity industry (Bunn, 1998).
- Focussing the attention of government on industry regulation and in a few cases also performing indicative planning for expansion.

As a result of reforms, competition has been promoted at the final user's level, allowing consumers to purchase electricity freely, which has reduced electricity prices, creating incentives for demand but conflicting with Demand Side Management -DSM- policies. DSM encompasses planning, implementation and follow-up activities, with the purpose of modifying levels and patterns of electricity consumption. By means of these programmes, important benefits have been achieved by both end users and power companies, especially with respect to: energy efficiency initiatives, direct load control, load interruption and hourly pricing (EIA, 1996).

However, it is not clear as to whether the conditions for rational energy use under centrally planned set-ups, still prevail when markets are liberalised. In the following section we explore this issue as it has been reported in the literature that customers are not behaving rationally

according to the Neo-classical precepts with respect to electricity efficiency-use. In section 3, we use the Institutionalist approach to economics, in the form of bounded rationality, and propose a decomposition of the decision-making (DM) mechanism for customer choice, intending to account for the apparently “irrational” energy consumption of customers. Section 4 presents models that better explain consumption patterns and show likely policies for overcoming some of the consumers’ limitations. Section 5 illustrates possible traders’ strategies that may be implemented, along with government policies that may contribute to accelerate efficiency in the market place. Final conclusions are presented.

2 EFFICIENCY AND RATIONAL ENERGY USE UNDER OPEN MARKETS

Under a competitive environment, companies cannot be forced to undertake programmes of demand side management or efficient production. For environmental and efficiency reasons, governments may seek incentives but cannot force utilities or final users to undertake such programmes (Jaccard, 1995). Utilities and electricity companies would only offer such programmes if they could benefit from them, but which along the production chain are those companies? To provide answers to this question it is important to examine the likely incentives to the industry.

Transporters usually pursue efficiency programmes, intending to reduce losses at economic levels. As regulated revenues depend on transported energy, the business logic seems simple: transport as much as possible. Thus, they do not seem to benefit from promoting a reduction in the level of consumption of end-users.

Generators gain from efficiency and production “optimisation”. For this activity, regulators encourage highly competitive markets, which provide signals for generators to produce at “optimal” levels, if they are to survive in the market place.

Traders may have incentives towards undertaking DSM programmes. However incumbent agents might naturally consider different strategies from new entrants to the business. As

competition turns intensive, product differentiation will create opportunities for incumbent traders who may approach it, by:

- Implementing efficient energy-use programmes for consumers by means of binding contracts,
- Promoting efficient energy use to reduce demand when prices in the wholesale market are higher than those that were previously agreed with customers, and
- Promoting efficient energy use in those sectors of society where electricity is subsidised by law.

With respect to new traders in this industry or those who intend to increase their market share, they may:

- Promote efficient energy use as part of a strategy to attract clients.
- Promote efficient energy use as ESCOS –Energy Service Companies– do.

The above possibilities provide elements for arguing that open markets need not necessarily discourage programmes of “rational” energy use and efficient production. It is not clear though as to when and which agents would undertake demand side management and efficiency programmes, under open markets, because of possible market barriers.

Sioshansi (1995) considers that under open markets DSM programmes should operate better than under centrally planned schemes. To understand the grounds of this assertion, let us revise the evolution of DSM, based on Sioshansi’s perspective. He identifies three periods for DSM:

1. 1973-1989 Command and control without incentives.
2. 1989-1994 Command and control with incentives.
3. 1994 - Consumer driven to achieve better efficiency.

The third period for the DSM is marked by two events that can completely change the concept of the electricity business: competition in the trading business and free access to distribution networks. Sioshansi argues that under market schemes, DSM can be more effective than ever before. However the literature has already reported some difficulties. Several researchers have noticed that substantial differences exist among the current levels of energy efficiency and those that should exist if they had undertaken the appropriate decisions under a rational approach. This problem is referred to in the literature as “the energy efficiency gap” (Jaffe and Stavins, 1994), which will be discussed next.

The effectiveness of market mechanisms in reaching socially desirable levels of energy efficiency has generated a debate among economists and policy makers. The Neo-classical assumptions of perfectly informed markets and rational individuals that consider all costs, when deciding what appliances to buy, seem insufficient for understanding the effectiveness of DSM.

When observing electricity consumption, agents seem to implicitly assume discount rates above 89%, which are much higher than those rates applied to other common investments (Hasset and Metcalf, 1995; Howart and Andersson, 1993; Hausman, 1979; and Gately, 1980).

Some authors claim that consumers apply high discount rates, due to price and operation uncertainties, when acquiring some appliances and domestic technologies. Others argue that these high rates may be explained by the consumers’ low revenues and their lack of means for investment. Both imply that consumers expect to recover investments in very short periods of time, which can be overcome by: a) providing guarantees and b) subsidising customers who have low incomes. In this respect, a critical issue consists of establishing the size of the energy gap and the definition of the optimal level of energy efficiency (Jaffe and Stavins, 1994).

Apparently some market inefficiencies are due to uncertainties and to other matters related to the decision-making processes of final users, including: cultural barriers, aesthetic parameters, habits, asymmetric information or knowledge and high risks. It is with respect to these issues that bounded rationality (Simon, 1979) and desires and opportunities (Elster, 1990a) seem to

provide insights for undertaking demand side management and energy efficiency, under bounded conditions, referred to as rationally-bounded energy-use, which we will examine next.

3 DECISION-MAKING FRAMEWORKS

As the problem of achieving market efficiency is grounded in the decision-making mechanisms adopted by economic agents, it is important to note that two distinct approaches have been followed in the economics literature. On the one hand, Neo-classical economists argue that individuals maximise their utility function, which means that as absolutely rational agents they possess all the information they require for assessing their options. On the other hand, Institutionalists largely acknowledge an uncertain future and other limitations in the decision-making process that turned individuals into satisficers rather than optimisers (North; 1990; Simon, 1959; Hodgson, 1998; and Conlisk, 1996).

As the former hypothesis has not fully accounted for the efficiency gap previously discussed, we examine in this paper the likely constraints that customers may confront when consuming electricity, and investigate alternative policies that may lift some of the constraints that consumers confront. We take this path by connecting North's (1990) and Simon's (1959) approach with Elster's (1990a) view of decision-making. In order to illustrate the main characteristics of bounded rationality models let us start with the problem of selection.

A simple way of explaining an action is to consider it as depending on two successive filtering operations (Elster, 1990a). The initial step begins by enquiring about all possible alternatives that the individual can undertake. The first filter comprises all the physical, economic, legal and psychological restrictions that the decision-maker faces. After this filtering operation, we are left with an opportunity set. The second filtering operation determines which elements are included in the set of desires, see figure 1.

We can observe that because of the first filtering operation, the selection may not be carried out to the second filtering operation. This could be the case if the opportunity set were reduced to an empty set after the first step. It is important to realise that it is usually easier to change people's opportunities than their way of thinking. Desires and opportunities can influence each other and they can both be influenced to produce an action, as illustrated in figure 1.

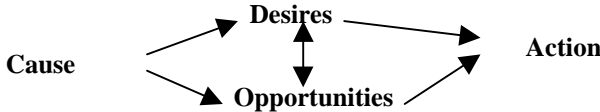


Figure 1. Desires and opportunities

Opportunities are more basic than desires in one aspect: they are easier to observe. The military strategist states that his plan should be based on the enemy's capacity (verifiable) rather than on his intentions (unverifiable) (Sun Tzu, 2001). This means, getting ready for the worst case, in which the enemy will harm us as much as he can possibly do.

When facing a decision, a person usually does what he believes is best for him. This sentence, deceptively simple, summarises the theory of rational decision-making (Elster, 1990a).

According to Elster, for an action to be rational it should be the result of three optimal decisions. First, it should be the best means to carry out one person's desire according to his beliefs. Second, these beliefs should be optimal given the evidence that the person has. Finally, the person should gather a good amount of evidence, neither too much nor too little. The correct amount depends on his desires, the importance assigned to the decision and his beliefs about costs and benefits.

Since opportunities are unknown to the decision-maker, the final action is the result of his desires and beliefs rather than opportunities. When facing a decision, we confront the risk of acting too soon with too little information versus delaying the process while gathering information, until it becomes too late. This process is shown in figure 2.

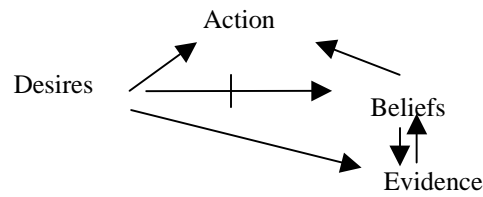


Figure 2. Optimisation process in rational decision-making (Elster, 1990b).

However, not optimality but rather intended optimality may better explain decision-making (Simon, 1979). Figure 3 shows that only part of the opportunity set is known to the decision-maker, as he just has certain evidence about their existence, depending on his beliefs. The decision-making mechanisms will be adjusted to Simon’s (1979) framework, consisting of finding a satisfying set constituted by the overlap of opportunities, desires and beliefs.

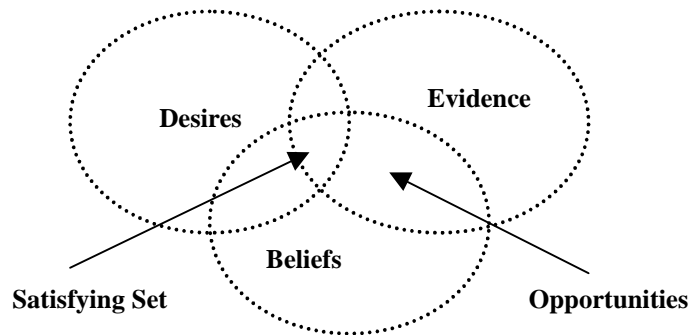


Figure 3. Set of desires, opportunities and beliefs.

Furthermore, Simon (1959) argues that decision-making is necessarily bounded because of the limited processing capacities of human beings and the failure of “absolute” rationality to account for the consequence of physiological or sociological factors intervening in the process. There are, however, other elements involved in the DM process, such as anticipating future preferences, that are often confusing and subject to substantial error (March, 1988).

The logic is to establish a set of rules that facilitates the progression from an unknown condition to one which is known (León, 1994). The problem is to define what is true in a

series of situations and to establish limits. For example, the expression “the water is hot” becomes true under certain circumstances in a specific environment. Also, this logic does not establish what is true or false, but rather provides thresholds as is done in fuzzy logic (McNeil & Thro, 1994).

Human intelligence does not work as this logic prescribes. According to Simon (1979), human beings are fundamentally adaptive to the environment. An environment of high complexity would paralyse a totally logical system, forcing the decision-maker to discard a large amount of information. In highly complex environments, calculations should be made by procedures that allow us to reach the objectives on time, although not always providing the best or optimal solutions.

Against this background, two important characteristics of the problem solving process must be considered (Simon, 1979; Rubinstein, 2000): a) mental representations are supported in work-memory with finite capacity only, and b) human decisions differ from computationally logical systems, since they are affected by the environment. While computers disregard context, humans seem to integrate it better into their decision-making processes. Is it then correct to attribute full rationality to individuals and to model them under these assumptions?

In organisations, although individuals do not behave totally rational, they intend to do so- this is still denoted as rationally-bounded behaviour. In this paper we emphasise the importance of bounded rationality in the decision-making process for better policy modelling. In the next section we address this issue, by proposing a modelling scheme which consists of a synthesis of Elster’s and Simon’s approaches, as it has been recognised that there are important links between the two (Cook, 1990).

4 MODELLING CONSUMERS’ DECISION-MAKING IN ELECTRICITY MARKETS

In previous sections we have argued that Neo-classical economists have not completely been able to explain the efficiency gap that has been observed in electricity markets. Pursuing Elsters's ideas, under the Institutionalist framework, in this section we build a modelling approach that may help us understand the rationality of energy consumers, in order to propose policies and strategies intended to make energy use more efficient.

This approach is centred here on the problem of understanding the decision-making processes, with respect to energy efficiency, of the most relevant agents concerned with energy consumption - traders and end users - for most effective policy making.

In this paper we will focus on the likely limitations of traders and final users and investigate the effect of these limitations on electricity consumption. Policies evaluated in this paper are geared towards overcoming the barriers of final users to the adoption of certain types of energy-efficiency technologies. In this sense, this line of research may support traders' strategy intents, regulators' initiatives or government policies.

Bounded-rationality modelling claims to overcome some of the deficiencies exhibited on classical approaches, when addressing efficient energy use and DSM policies. In general terms, this would be supported by March (1988), as he states that "pure models of rational choice seem obviously appropriate as guides to intelligent action, but more problematic for predicting behaviour". Others have further argued that the classical approaches are ineffective (Bunn and Dyner, 1996; Dyner, 2000), as they are:

- Normative
- Linear
- Non-systemic
- Stationary

In this context, these features become requirements for modelling methodologies. To improve our understanding about demand evolution and the interactions between traders and final users, approaches also need to support simulation capabilities for policy assessment. This

research expects to improve our vision with respect to technology diffusion, “rational” energy use, and energy efficiency, under a deregulated environment and strong competition among traders.

The previous section established that desires and opportunities drive decision-making processes. It also observed that limitations in decision-making may be explained by bounded rationality, some of which might be lifted by the action of traders. These, in turn, depend on both the environment and own goals, customers’ feed-back, via system reaction, and by adjustments made to government policies and traders’ strategies. This general decision-making framework is represented in figure 4. The system evolves according to the actions of participants. The observed system evolution induces government policies, according to set goals, in order to modify customers’ desires and opportunities. This framework uses the inherent sociological and psychological limitations of consumers.

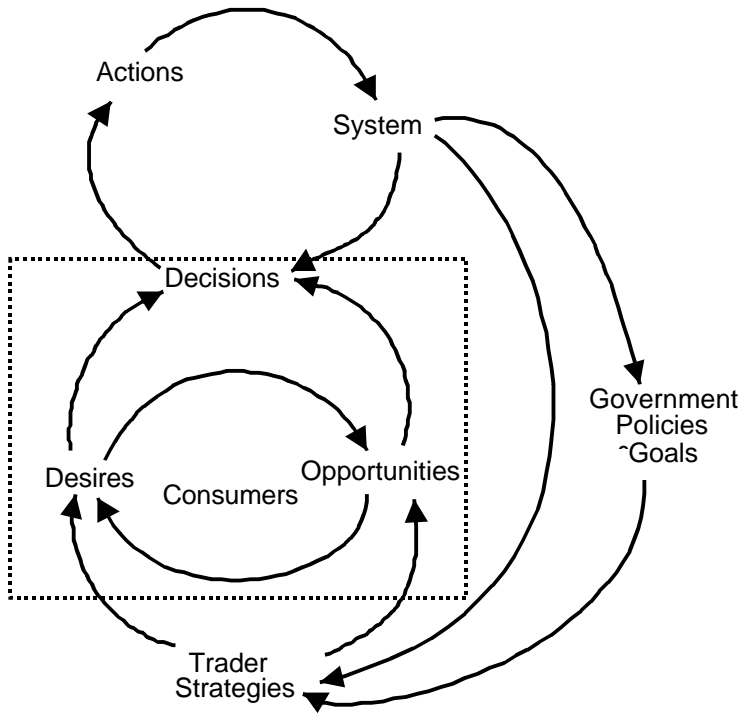


Figure 4. General system scheme

In this context, there is a need for models that may appropriately support policy assessment with respect to “adequate” energy consumption, and which need to incorporate bounded rationality under market conditions. When evaluating modelling alternatives for policy support, the literature provides foundations to carry it out using simulation and systems dynamics. On the one hand, Bunn and Dyner (1996) and Larsen and Bunn (1999) state that system dynamics may be a sensible option, especially if operating under rapidly evolving systems or under recently restructured markets. Furthermore, Morecroft (1983) argues that systems dynamics implicitly uses bounded rationality frameworks, and that the behaviour of complex organisations can only be understood by taking into account the knowledge of individuals and their psychological limitations. Also, Pidd (1997) shows the advantages of soft methodologies approaches in this kind of problem. On the other hand, there is a range of perspectives on the problem, going from agent-based simulation (Bunn and Oliveira, 2001; Bower and Bunn, 2000) to game theory (Ferrero *et al.*, 1998). All these perspectives focus on information flows within complex systems, the quantity and quality of the information that is manageable in the decision-making processes and the decision rules being used.

It is at the level of information flows and decision-making where most of the fundamental ideas of bounded rationality coincide with simulation techniques, but it is also at this level where bounded rationality takes a different view from classical approaches. This turns specific with respect to desires and opportunities in the selection of efficient technologies.

In this paper we undertake a simulation modelling approach for better explaining consumers’ decision-making processes, under bounded rationality conditions. The simulation model that represents decision-making considers: desires, opportunities and the decision-making mechanism itself, as discussed next.

4.1 Determination of Opportunities

Modelling begins by establishing the set of all opportunities (i.e. determining all possible decisions that the individual can make). This set may be reduced because of the technologies

that are available in the local market (see figure 5). In turn, this set of technologies is limited by the technologies that the decision maker considers. The set of real opportunities is finally reduced by the economic limitations of end users. With this vision, modelling opportunities can be approached by reducing values gradually, before reaching a decision.

4.2 Determination of Desires

Modelling desires consists of determining the portion of the population that will not be shifting away from former energy technologies because they have no knowledge about alternatives, or because they are reluctant to change (and they may not even consider the possibility of change), or even because they are risk averse. All these inhibit the entrance of technology alternatives (see figure 5).

There are some problems related to modelling. Perhaps the main one is that related to modelling habits, which seems to be an important factor against technological changes. The general diagram, in figure 5, describes the filtering processes of desires and opportunities. The filter of opportunities illustrates how decisions consider product availability, information about alternatives and economic welfare of customers. The filter of desires includes customers' habits of, and their willingness or stimuli required for, change.

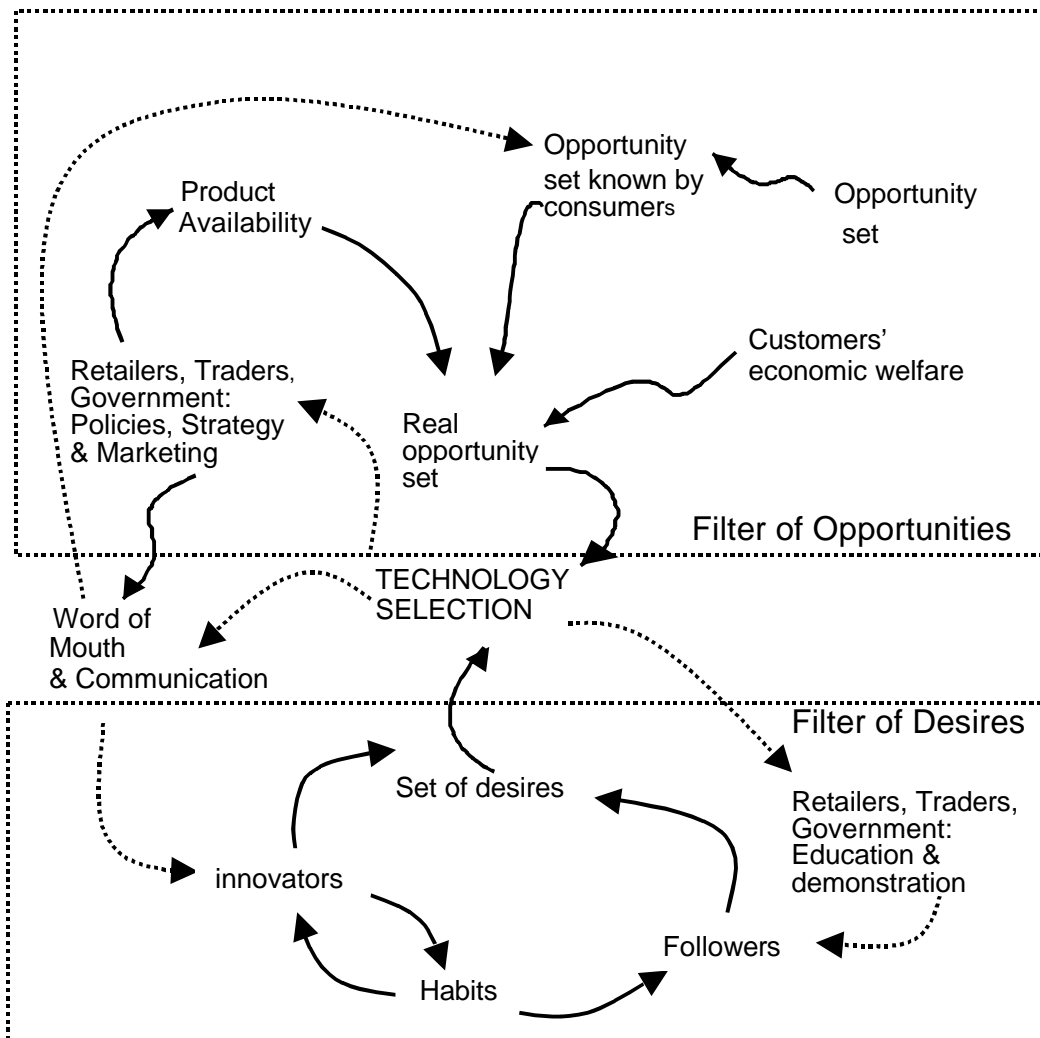


Figure 5. Double filter for technology choice

4.3 Establishing limits for decision-making

When individuals confront decision-making with no limitations, a reasonable assumption is that they intend optimality. This can be a sensible supposition as limitations have already been filtered. This assumes that a decision-maker takes the best option, under the information available to him. Bounded rationality, however, might be a more appropriate framework since it better incorporates desires and opportunities, as discussed in previous sections.

For the evaluation of investment decisions, it is necessary to re-state the concepts of annual equivalent costs, net present value, monthly equivalent cost, operational costs, and investment costs, among others.

Policies intending to stimulate opportunities

Policies intending to stimulate opportunities are easy to identify as “Opportunities are external to individuals, while desires depend on them”, Elster (1990a). It is easier to change people's opportunities than to transform their way of thinking. Policies intended to increase opportunities, counter the causes that restrict them. The different policies that may enlarge the opportunity set include:

- For the set of reduced opportunities: Research and development of new technologies.
- For the set of opportunities known to user: Diffusion or marketing.
- For the set of real opportunities: Improvement of distribution channels of technologies.
- For the set of economic opportunities: financing, soft credits.

Policies intending to stimulate desires

There is no use for an extensive opportunity set if people have limited desires. To focus on policies that stimulate desires it is necessary to consider people's habits, intending to modify them. This could be accomplished by means of education or by demonstration (pilot schemes). Changing habits may sometimes be easily achieved by children's education.

5 MODELLING ENERGY CONSUMPTION UNDER BOUNDED RATIONALITY

We will now turn to alternative modelling of consumers' decision-making under bounded rationality and compare this with full rationality, using The Logit Model and Financial schemes. The initial problem under consideration is the market split between incandescent and fluorescent compact light bulbs.

Market split is established according to the following rationale: the variation in the number of consumers that embrace a particular appliance or technology depends on new adopters and the

ones that stop using it. Individuals adopt a particular technology with probability PE_i , with time-delay l , and discards it with probability PA_i , as described by the following equations:

$$\frac{dTec_i(t)}{dt} = Input_i(t) - Output_i(t)$$

$$Input_i(t) = (MarketSize(t-l) - Tec_i(t)) * PE_i(t-l)$$

$$Output_i(t) = Tec_i(t-l) * PA_i(t-l)$$

Tec_i : Installed technology i .

PE_i : Probability of selecting technology i .

PA_i : Probability of discarding technology i

t : Time.

l : Delay.

Alternatively, with respect to the probabilistic approach, we may assume that decision-makers are either absolutely rational with respect to price, and choose the cheapest items, or that they make their choices depending on a variety of attributes of such items. In the former case we would use a simple optimisation rule consisting in selecting the item with lowest price, whereas in the second case we use a Logit model, as described below.

Optimisation: If individuals were optimisers, everyone should switch to compact fluorescent bulbs, as they would attain lower annual equivalent costs. This would obviously be impossible because of production, technological and cultural barriers.

Logit Model: The Logit (logistic probability unit) model is used for decision-making analysis and is probably the most widely used model in practical applications (Bierlaire, 1998). It considers the probability of choice when the attributes of a technology are compared with respect to the attributes of other technologies. The logit equation is represented as follows:

$$PE_i = \frac{AEC_i^{-g}}{\sum_j AEC_j^{-g}} \quad i = 1, 2, \dots, k; \quad j = 1, 2, \dots, k.$$

i: Source or technology.

AEC_i: Attributes: price, color, fashion, status, size, etc.

The results obtained with the Logit model using just the price as attribute, can be seen in figure 6. The market share of compact fluorescent bulbs is larger than the one of incandescent bulbs, but does not penetrate the whole market.

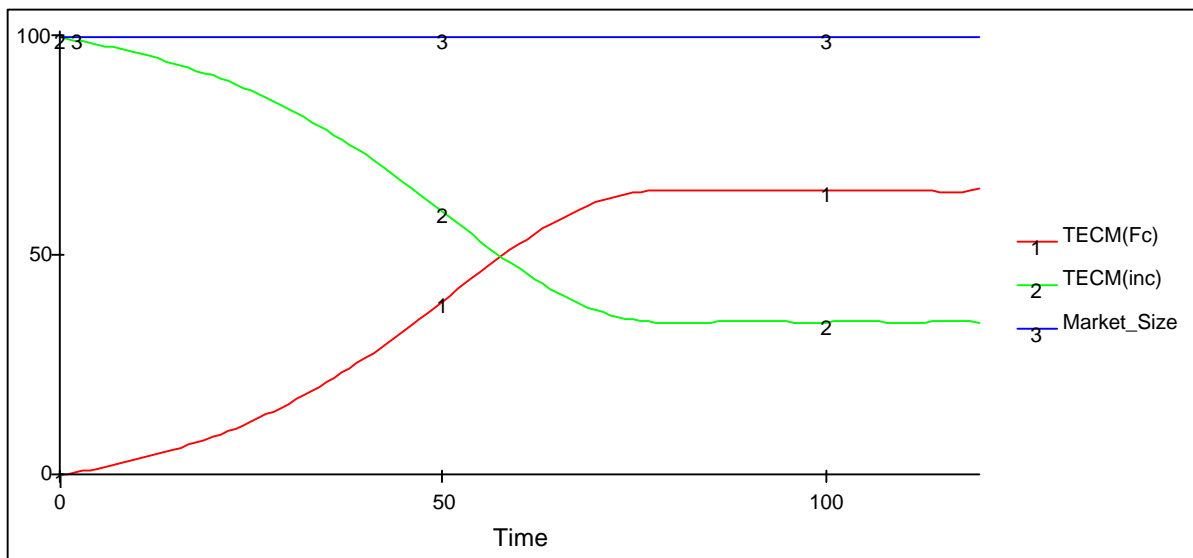


Figure 6. Technology propagation of light bulbs using the logit model

Financial decisions: When modelling financial decisions, such as future value, one could determine the discount rates at which compact fluorescent bulbs would be most attractive. In this case, the model uses the same principle as the logit model, however present value is used instead of the annual equivalent cost, to incorporate the concept of risk, via discount rates.

$$FV = PV * (1 + r)^n$$

r : Discount rate.

FV: Future value.

PV: Present value.

n : Number of periods.

Figure 7 shows model results when financial decisions are made, under discount rates of 10% and 50% respectively. Haussman (1979) and Gately (1980) found that households apply discount rates above 100% when acquiring appliances. These discount rates differ between appliances, for example while electric water heaters' implicit discount rate is 243 percent, a freezer's is 138 percent (Haussman, 1979). There are two other explanations for purchases of inefficient appliances: lack of information and lack of liquidity. In the US, while appliances are relatively inefficient, partly due to lack information to customers, there do not seem to be major acquisition barriers, as credit is widely available (Thaler, 1992). Results are as expected: to lower discount rates, increase penetration of the corresponding technology. These high discount rates could be reduced by means of educational programmes.

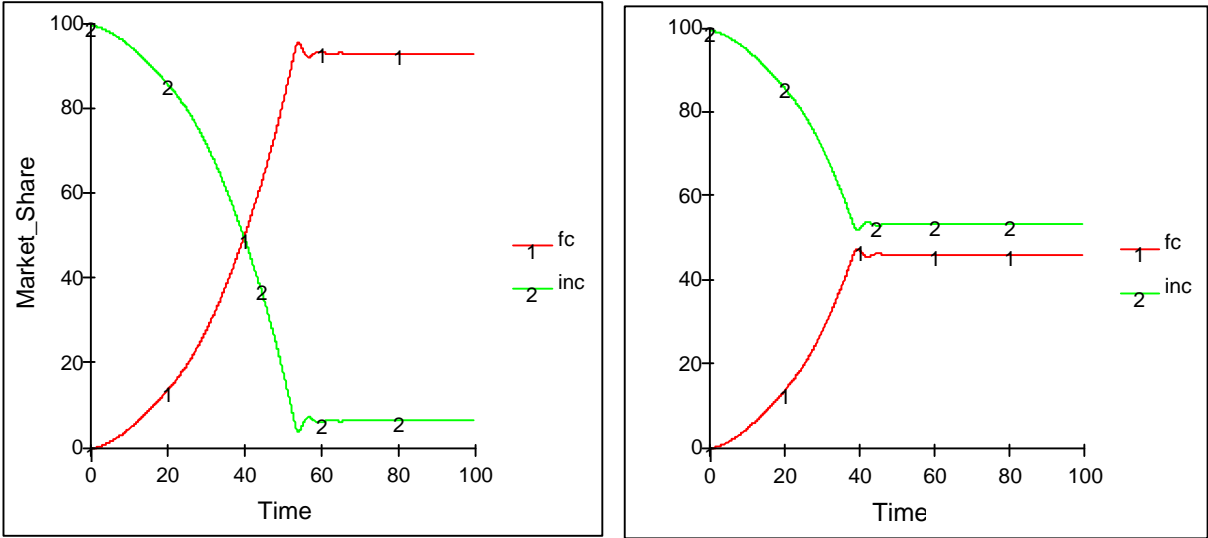


Figure 7. Results of the financial model for discount rates of 10% and of 50%, respectively.

When considering technology diffusion mechanisms that affect acquisition decisions (on top of financial arguments), where individuals are followers, and never take their own decisions,

the equations below explain the rate of propagation of a particular technology or fuel. This behaviour has been referred in the literature as contingent behaviour (Schelling, 1978).

$$\frac{dAT_i(t)}{dt} = Followers(t) * Propagation\ rate$$

$$Followers(t) = Followers(t - l) * Growth\ rate - Followers * Propagation\ rate$$

AT_i(t): Acquisition of technology i at time t

Followers(t): Population whose behaviour depends on what others are doing at time t

Model results can be seen in the figure 8. These results contrast with findings exhibited in figure 7. This is due to the fact that only a small percentage of the population is capable of making decisions because of their lack of knowledge or fear of change. However, we expect to experiment with a propagation process that will help defeat the incumbent technology.

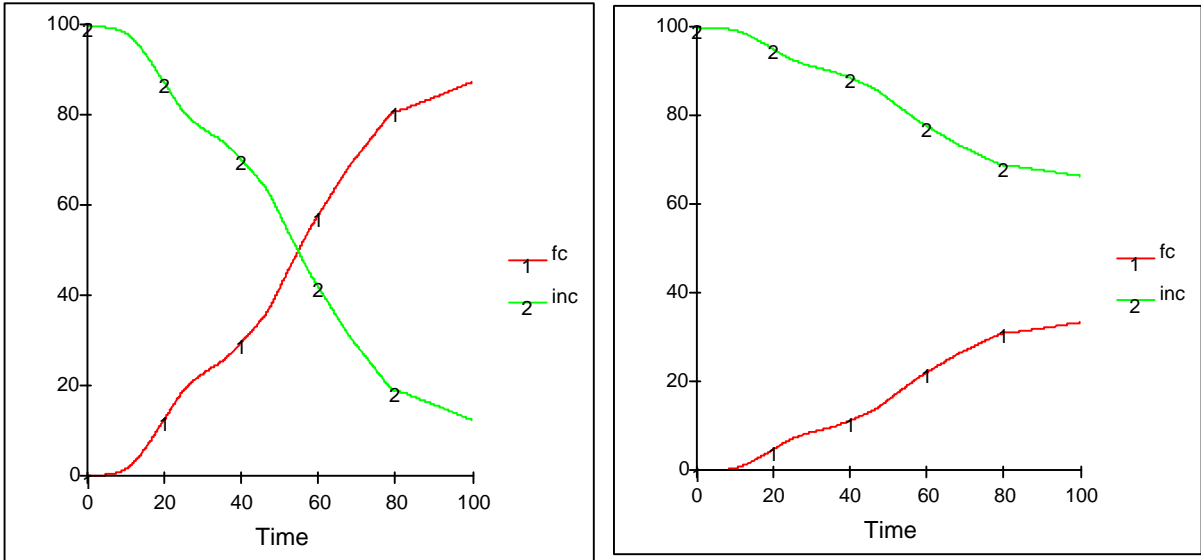


Figure 8. Technology propagation when 8% of the population considers changing, using discount rates of 10% and 50%.

In the following section we report how the modelling approach presented here can not only explain technology penetration of compact bulbs in the UK but also natural gas penetration in the residential sector in Colombia.

6 BOUNDED RATIONALITY AND ELECTRICITY TRADING

The liberalisation of energy markets has had profound implications for electricity trading, market evolution, company strategy and government policy. On the one hand, there has been fierce competition in the market place, where price and rudimentary forms of service improvements have initially played an important role during the infant stages of the development of the new markets. On the other hand, it has not always been possible for governments to layback and wait for markets to develop on their own. Long term strategic issues, such as supply additions and demand side management, have also been considered as society is notably sensitive to these issues, especially with respect to their effect on the environment. In this section we examine examples of the proposed approach, with respect to both cases.

6.1 Penetration of efficient light bulbs in the UK

The end-users' market has been gradually liberalised in England and Wales since 1990. Initially only large consumers could choose their suppliers; later, in 1994, medium-sized customers were allowed to do so, and finally households and the rest of small consumers were freely allowed to choose electricity supplier. It took three years for over half of large and medium- sized consumers to move to alternative suppliers, and their bill were reduced by about 20% (Littlechild, 1998). For the household sector, changes have occurred at a rate of over 100,000 per week (Ofgem, 2001). This in itself prompts interesting research issues related to consumers' behaviour. However, what draws our attention in this paper is consumers' behaviour towards energy efficiency, which we will examine next. In particular we address the issue of penetration of efficient light bulbs in the UK.

In general, barriers to inertia may easily be lifted when customers almost immediately experience the effect of their decisions. As has just been discussed above, electricity prices have provided a clear signal for UK customers to change providers, nevertheless this has not always been the case in all cases and circumstances (Goett *et al.*, 2000). For example, in terms of energy-efficiency issues, such as light bulbs, customers have not always shifted to the most “rational alternative”, because of a number of possible barriers, as will be discussed ahead.

In the UK, before 1993 less than 10% of the population had at least one compact florescent lamp (CFL). By 1997 penetration had reached 23% of the market (figure 9 indicates the historic penetration). This was basically the result of consumers’ increasing awareness that rose from 50% in 1993 to 75% in 1997 (Martinot and Borg, 1998).

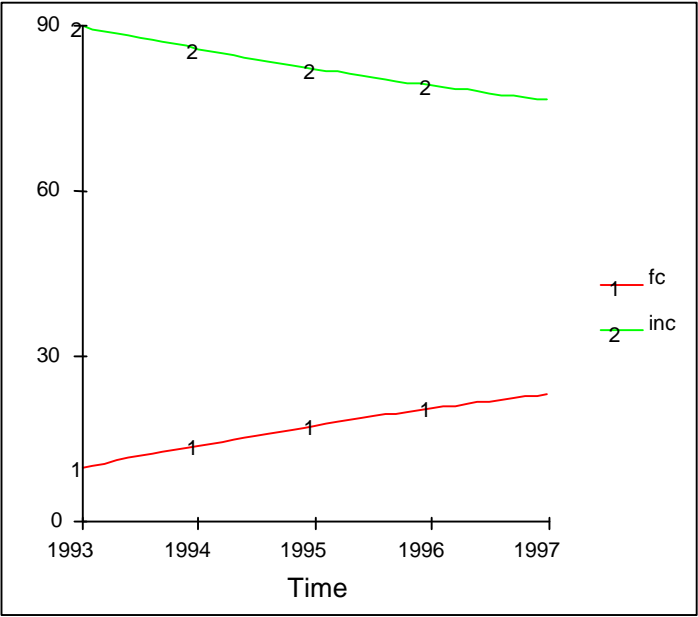


Figure 9. Penetration of CFLs(fc) in the UK and loss of market of incandescent lamps (inc)

However, important barriers to a higher penetration of the CFLs have emerged. The most important ones include (Martinot and Borg, 1998; Palmer and Boadman, 1998):

- Lack of information

- Cost
- Lack of incentives and
- Disbelief about the characteristics of the technology.

Figure 10 show results of policy simulations geared to: a) reductions of the consumers' discount rate, via exhibition programmes, advertising and product guarantee, and b) subsidising CLFs by as much as one half of the price.

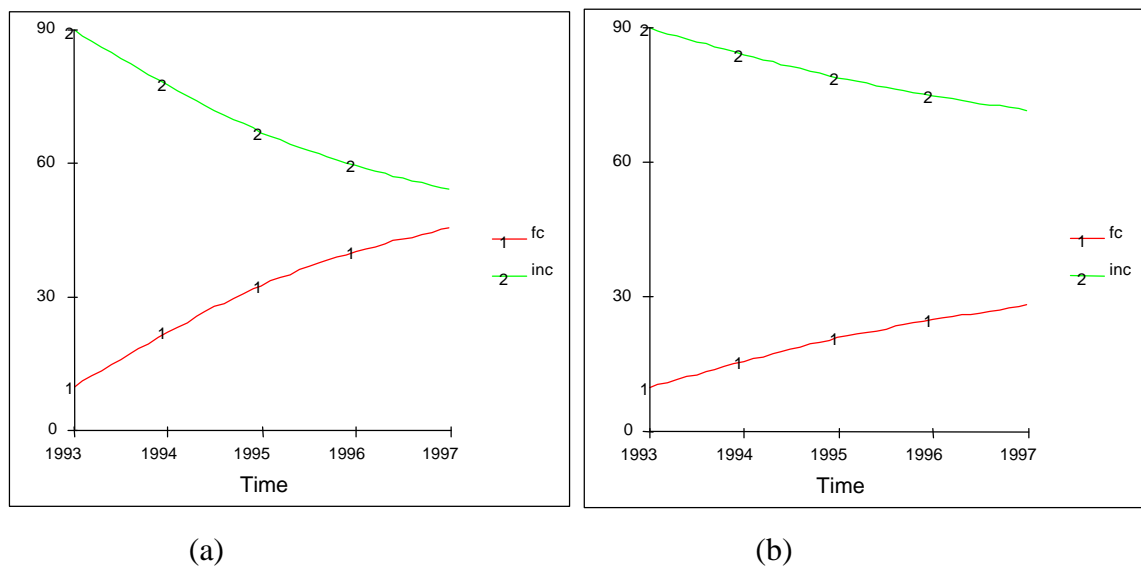


Figure 10. Likely impact of the penetration of florescent bulbs under a) demonstration programmes and product guarantees, and b) subsidies

These results suggest that price reduction of florescent lamps would not make much difference, as they will still be much more expensive in absolute terms than incandescent lamps. However, demonstration programmes and guarantee schemes may have an important impact on the penetration of florescent lamps. With appropriate marketing, penetration could be at even higher rates, as has happened in the mobile telephone industry.

6.2 Penetration of natural gas in the household sector in Colombia

The penetration of natural gas in the household sector in Colombia provides a second case for illustrating how bounded rationality has an effect on decisions with respect to energy-

efficiency issues. This case shows that government goals might sometimes be outperformed, when there is intensive competition or incentives are rightly placed (volume sales and profits).

In the early 1990s the Colombian government decided to promote the use of natural gas in the household sector, especially for cooking and water heating. It structured a plan which included setting in place a gas transportation network, as well as the legislative industry-framework for production, distribution and pricing (LEY 142, 1994). Note that in some Colombian regions, sales to end-users have been a highly competitive business.

The question of the speed of gas penetration has been of especial interest as this has a major impact on the finances of investors. Initial calculations indicated that the annual equivalent costs of electric cookers and water-heaters were much higher than for gas-fired ones, providing the right incentives for shifting source were established. The price of natural gas for residential users is about US\$7 per MBTU, while for electricity it is nearly US\$39 per MBTU. However, some likely barriers have been detected for households, including:

- Entry expenses
- Habits
- Availability

To counter these barriers, subsidies, instalment payments and exhibition programmes were put in place. As a result, penetration has been about 18% per year during the period 1994-2000, which is higher than originally planned. Nevertheless, this could have been even higher if more connections and other programmes had been available to customers (see figures 11 and 12).

Figure 11 shows simulation results for the energy source that residential consumers choose for cooking. It can be appreciated that traditional electricity falls at the expense of all other sources. We can also observe in figure 12 the actual gas penetration in the residential sector, the planned penetration that the government envisaged and a number of other scenarios, including one that makes available 120% of the planned number of installations to customers.

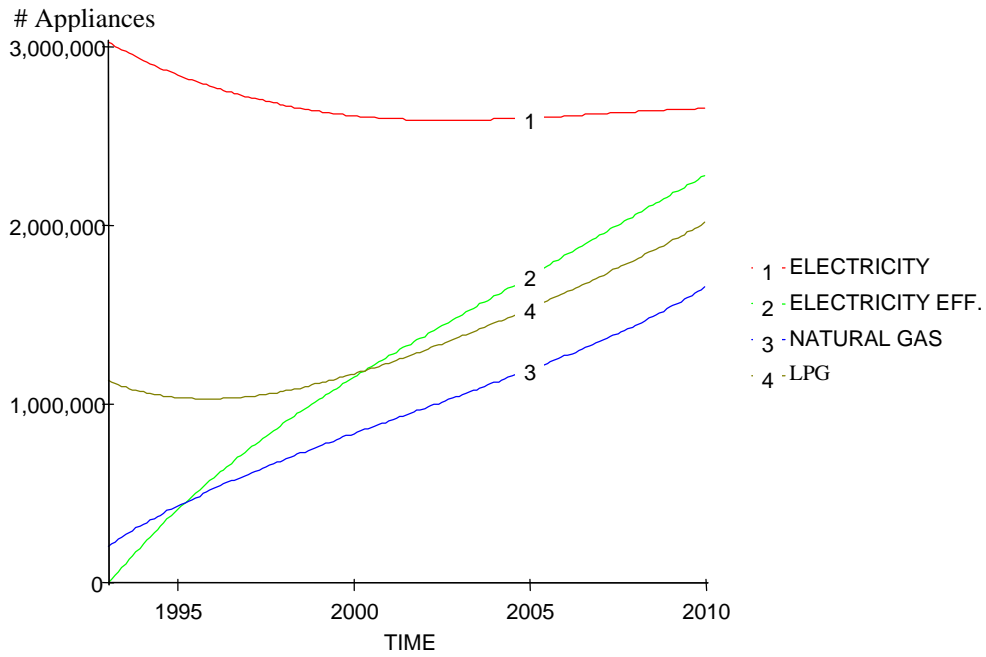


Figure 11. Simulating the evolution of stoves, by source of fuel, in Colombia

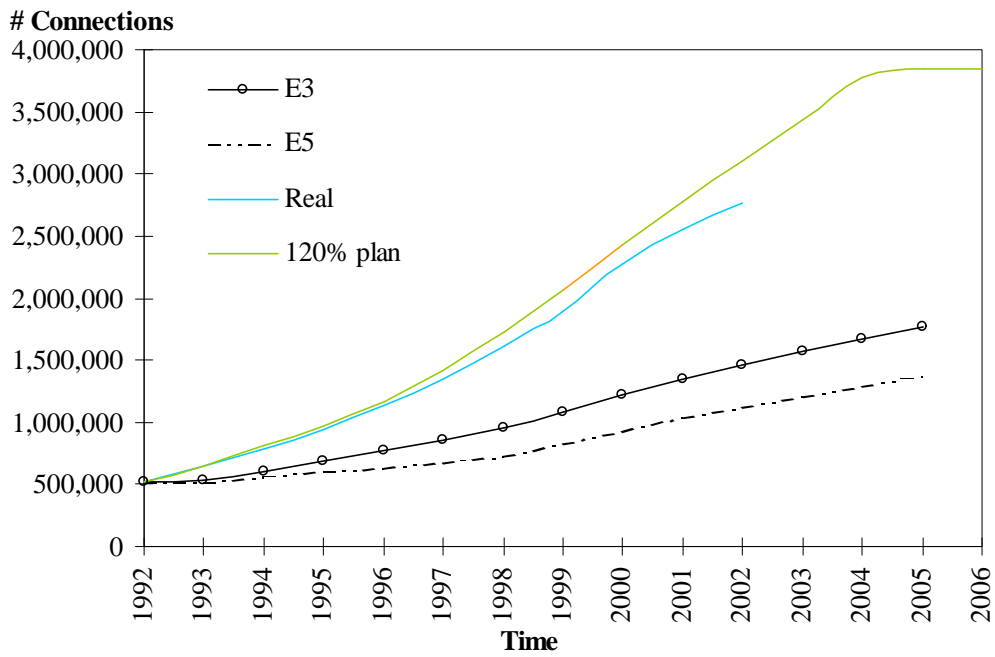


Figure 12. Natural gas penetration in Colombia

Plan implementation has been successful as loans, financial services and demonstration programmes have been widely available to households. Simulation results indicate that the gas plan was outperformed because connections to the transport network were widely available to customers.

7 CONCLUSIONS

We have shown that the supposedly “irrational” behaviour of consumers with respect to electricity consumption, apparently manifested by the electricity gap that has been reported in the literature, is partly a fallacy grounded in customers’ bounded rationality.

We have analysed the decision-making process undertaken by consumers, in order to understand the rules and habits that have major influences on their behaviour. We did this to make explicit the likely barrier to the adoption of efficiency fuels, appliances or technologies.

The proposed approach provides grounds for the understanding of such consumers’ limitations and habits. We have examined alternative government policies and traders’ strategies that might lift customers’ barriers. We also considered the impact of advertisement, demonstration programmes and word of mouth on technology propagation. We indicate that these strategies may make important contribution to changing habits. Simulation results show that the efficiency gap may be closed under such policies.

The case of slow penetration of compact florescent bulbs in the UK might be partly explained by the lack of incentives to customers, including the high entrance cost. The Colombian case related to natural gas penetration has been successful, as incentives have been correctly placed, rapidly eliminating entry barriers, which contributed to leaving behind the goals that once were set.

These cases illustrate how policies could be geared to influencing customers’ desires and opportunities, lifting some of the penetration barriers to energy efficiency. These in turn will contribute to more sustainable forms of energy use, partly overcoming disputes between

marketers and conservationists. There is still room, under competitive markets, for policy incentives that contribute to lowering customer bills and energy-efficiency consumption.

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