An Agent-Based Simulation of Smart Metering Technology Adoption

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ABSTRACT

Based on the classic behavioural theory the "Theory of Planned Behaviour," the authors have developed an agent-based model to simulate the diffusion of smart metering technology in the electricity market. The authors simulate the emergent adoption of smart metering technology under different management strategies and economic regulations. Their research results show that in terms of boosting the take-off of smart meters in the UK electricity market, choosing the initial users on a random and geographically dispersed basis and encouraging meter competition between energy suppliers can be two effective strategies. The authors also observe an "S-curve" diffusion of smart metering technology and a "lock-in" effect in the model. The research results provide users with insights as to effective policies and strategies for the roll-out of smart meters in the UK electricity market.

Keywords: *Agent-Based Simulation, Behavioural Theory, Smart Metering Technology, Technology Diffusion, Theory of Planned Behaviour*

1. INTRODUCTION

Technology adoption, which studies the acceptance and diffusion of a new technology in a market or an economy, is an important research area in several disciplines such as marketing, management, industrial engineering and economics (Loch & Huberman, 1999). Although the invention of a new technology often comes into being as a single discrete event or a jump, the adoption of that technology often appears as a continuous, long and slow process (Hall & Khan, 2003). A new technology will contribute little in a market or economy until it has been adopted by many users. Therefore, understanding the process of the diffusion of a new technology is of great significance. Rosenberg (1972) points out two characteristics in the technology diffusion process: overall slowness and wide variations in the rates of acceptance of different technologies. Rogers (1962) theorizes a classical technology diffusion model—the S-curve model of spreading innovations, which suggests that the early users adopt a new technology first, followed by the majority, until the technology becomes common. This model has been successfully justified by studying the

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adoptions of new technologies in many industries (e.g., Gurbaxani, 1990; Hayashi & Klee, 2003). Currently the studies of the diffusion of new technologies mainly focus on econometric models (e.g., Baldwin & Lin, 2001; Bandiera & Rasul, 2003; Weinberg, 2005). However, as suggested in the Punctuated-Equilibrium Model of Technology Diffusion (Loch & Huberman, 1999) the diffusion of a new technology is a complex process influenced by a broad range of factors, such as organizational inertia, stable industry constellations, cultural "openness" and uncertainty in the evolution of the new technology. Davis et al. (1989) also point out that the acceptance of a new technology is highly related to consumers' psychological factors such as "perceived usefulness" and "perceived ease of use." Therefore, complexity science which studies how the micro-level individual behaviour gives rise to the macro-level collective properties of a whole system appears to be another effective means of studying the influences of factors in the complex process of the diffusion of a new technology.

In this paper, we present an agent-based model to study the adoption of smart metering technology in the electricity consumer market. The motivation of the study is triggered by the fact that the future of smart metering technology in the UK energy consumer market remains a key concern of the government (e.g., the Department of Energy and Climate Change (DECC)), the energy market regulator (the Office of Gas and Electricity Markets (Ofgem)), as well as energy suppliers and consumers. We target the issue by using agent-based computational simulation, i.e., we build a virtual society being comprised of rational software objects, the "intelligent agents," in a computer. These agents, representing both energy consumers and energy suppliers, interact in the virtual society. As with real households, the energy consumer agents make rational decisions in terms of choosing energy suppliers and metering technologies in the virtual society. Macro-level emergent properties, such as the evolution of the adoption of smart metering technology in the virtual society, can be seen as inferences of the adoption of smart metering technology in the real electricity consumer market.

The objectives of the study are twofold. First, we aim to provide an exploratory and predictive study of the future of smart metering technology in the UK electricity consumer market. Currently all the stakeholders, especially the government (DECC), energy market regulator (Ofgem) and energy suppliers, are all interested in promoting smart meters in the UK energy consumer market. However, a wide range of barriers and uncertainties make the future of smart meters unclear. A robust exploratory and predictive model can provide very helpful management intelligence for these stakeholders. In other words, the results from the model could potentially help decision-makers see the future of smart metering technology and establish effective strategies and economic regulations to boost the roll-out of smart meters in the UK electricity consumer market.

The second objective of the paper is to develop an effective multi-agent system framework on the basis of the classical psychological/behavioural theories to study all the complex phenomena in the energy consumer market. This model can be seen as a generic multi-agent framework based on which we can study the influences of a number of factors (e.g., word-of-mouth effects in a social network, consumers' perceptions, and the impact of random events) on the issues of most concern (e.g., issues about energy security, technology adoption and global warming) in the energy consumer market. For example, if we detach the model from smart metering technology and apply it to another issue, such as the diffusion of renewable energy technologies, it will still be an effective research approach. Moreover, because a key point in the development of the model—designing algorithms to control the behaviour and interactions of the electricity consumer agents, is based on the classical psychological/behavioural theories, the model can also be seen as another way of validating the classical psychological/behavioural theory.

The paper is comprised of six sections. The second section describes smart metering

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