Technology Diffusion of Smart Metering as an Energy Efficiency Information System

Wenjing YANG
Department of Building and Real Estate
The Hong Kong Polytechnic University
Hong Kong
(852) 34008130
w.j.yang@connect.polyu.hk

Patrick T. I. LAM
Department of Building and Real Estate
The Hong Kong Polytechnic University
Hong Kong
(852) 27665799
bsplam@polyu.edu.hk

ABSTRACT

Smart metering enables the optimization of energy consumption. People enjoy better energy efficiency and convenience with real-time consumption information and accurate billing. The resulting effects on energy conservation, reduced bills of consumers, and environmental friendliness are expected to contribute towards the achievement of urban sustainable development. As a smart system with the adoption of Information Communications Technology (ICT), the diffusion of smart metering should receive sufficient concern and recognition. The investment put into the smart metering installation needs to be rationalized with clear approaches for evaluating gradual diffusion of the technology. This research depicts the method for estimating the potential usage demand of smart meters. The effects of different variables influencing smart meters' adoption are also identifiable to help with the utility companies' promotion. With the prediction of future adoption, the roll-out of smart meters can achieve a better result. Besides, priorities and recommendations of smart metering diffusion are made to improve the implementation of smart meter projects.

Keywords

Smart metering; Technology diffusion; Energy efficiency; Information Communications Technology (ICT).

1. INTRODUCTION

Smart cities make use of Information and Communication Technologies (ICTs) as a driving force for social progress in modern society [1]. The innovation of the ICTs gives rise to new functionalities to help people enjoy a more convenient life. However, diffusion becomes a great perplexing problem with the increasing investment in ICTs. Governments pay great attention to greenhouse gas emission and take initiatives to achieve energy efficiency. The provision of information about cost savings, payback period and emission reduction leads to the improvement of energy management efficiency significantly [2]. As an energy efficiency information system, smart metering is regarded as an effective measure. Smart meters provide nearly real-time consumption information and accurate billing to the consumers and utility companies, which enable the optimization of energy usage and management. People enjoy a more convenient life, while the energy operators improve efficiency and reduce labor costs. Smart metering is developing fast in recent years with the wide application of wireless technology. A great share of investment has been put into the smart metering projects. However, the presumed adoption is usually not achieved as expected. The diffusion rate should receive sufficient concern and recognition in the studies of smart metering. The approaches of gradual diffusion of energy-efficiency technologies need to be rationalized for decision-making. Several models, including the Bass model and the Norton-Bass model, for predicting potential usage demand are proposed in this paper. Then smart metering diffusion is discussed based on the diffusion models. Summarizing from the success and failure experiences from different countries, the priorities and specific recommendations in the diffusion of smart metering will be given.

2. BASS MODEL

The potential usage demand of smart meters may be predicted with Bass Model. Bass Model is one of the core components about technology diffusion. The potential usage demand may be estimated based on the premise of a simple and elegant theory [3]. Bass Model was just expected to be applicable for consumer durables at the beginning, but now it is applied to forecast the diffusion of services and products with technologies significantly [4]. Product or service adopters are classified in 5 sorts as innovators, early adopters, early majority, late majority and laggards [3]. The later adopters are influenced by imitating pervious users who are called innovators at the beginning of the diffusion. The pressures of a social system increase the numbers of adopters. Bass formulated this assumption into a literary theory: $P(t)=p+(q/m)Y(t)$ in 1969 [3], where t is time, and q/m, p are constants. $Y(t)$ is the number of pervious adopters, and $P(t)$ is the adoption probability at time t. When $t=0$, $Y(0)=0$ and p is the probability of initial adopters at $t=0$, and states the coefficient of innovation. q is the coefficient of imitation, which reflects the pressure of a social system. m is the total potential demand. With the pervious installation of smart meters $Y(t)$, the numbers of adopters can be estimated. Thus, $S(t)=pm+(q-p)Y(t)-q/mY^2(t)$, $S(t)$ is the adoption calculated at time t [3].

The timing of technology diffusion can be depicted with the normal distribution, and the conditional likelihood of adoption presents a linear relationship over time with the previous installations. The potential usage demand can be measured with a S-shaped curve to describe and forecast the purchase growth with time [4]. The classic Bass Model can be depicted as follows [3]:

$$f(t)\,/\,(1-F(t))=p+qF(t) \tag{1}$$

$f(t)$ is the probability of installation at time t, $F(t)$ is the fraction of the ultimate potential adoption by time t [5]. Bass Model can predict the installation well without introducing the decision variables, for instance price, advertising, etc. [6]. The diffusion of smart metering can be reviewed with Bass Model as a helpful framework. The intuitive interpretations about smart metering diffusion may be derived. The installation status can be estimated as a function of time, and the timing at the peak is forecasted according to the theory. With the rapid development of technology, the life-cycle is also an important issue in the generational diffusion of digital technologies [7]. The implementation of smart meter project encountered the generational diffusion problems in the UK [8]. The first-generation smart meters were still in the progress of installation, while the second-generation has been under promotion, with the former being regarded as a waste of investment. An extension of the Bass Model can be used in the generational diffusion to adapt to the rapid upgrading of digital technologies [4]. For a single generation: $S(t)=mF(t)$, the adoption data of earlier generations may be used to predict a later generation with innovations. As an extension of Bass model, the Norton-Bass model for generational diffusion is represented as follows [4, 5]:

$$\begin{gathered} S_{1,t} = F(t_1)m_1[1-F(t_2)], \\ S_{2,t} = F(t_2)[m_2+ F(t_1)\, m_1]\, [1-F(t_3)], \qquad (2) \\ S_{3,t} = \{m_3+F(t_2)\, [m_2+ F(t_1)\, m_1]\}, \end{gathered}$$

and $m_i=a_iM_i$. For the ith generation service or product, M_i is the increased number of ultimate installations, and a_i is the average repeat adoption rate [4]. $F(t_i)=[1-\exp(-(p+q)t_i]/[1+(q/p)\exp(-(p+q)t_i)]$, where t_i is the time after the introducing the ith generation service or product [4]. Based on the installation status of previous generations of smart meters, the diffusion of the ith generation may be predicted with above generational diffusion model. With a generalized Bass Model (*Eq.1*), the number of the future adoption of smart meters can be estimated [3], which will help with the roll-out of smart meters. The Norton-Bass model of generational diffusion (*Eq.2*) may be used to estimate the adoption of different generations, which helps smart metering mitigate the problems arising from technological upgrading. Bass Model and Norton-Bass model can help with the decision-making of different implementation periods based on the previous installations of smart meters.

3. DIFFUSION MODELS

As an energy efficiency information system, smart meters' diffusion needs to be emphasized to achieve sustainable development. The influencing factors of smart meters' adoption should be identified to help with the utility companies' decision-making. The models of Theory of Reasoned Action (TRA) [9], Innovation Diffusion Theory (IDT) [10], Technology Acceptance Model (TAM) [11], Unified Theory of Acceptance and Use of Technology (UTAUT) [12] were developed with respect to the technology diffusion of information system [13]. Demographic attributes, for instance gender, age, and education level usually affect the acceptance of smart metering [17]. From the literature of energy consumption behaviors, the numbers of occupants, tariff and environmental awareness affect the installation of smart meters [18]. Structural equation modelling can interpret the determined parameters with respect to adoption based on the diffusion models. The significant variables affecting the potential usage demand may be found out [16], in that the effects of different variables influencing smart meters installation can be identified.

Davis indicated that the perceived usefulness, and the perceived ease-of-use by adopters affect the diffusion of an information system [11]. Users' perception based on the social psychology will affect the attitudes of adopters toward using. The attitudes then affect the behavioral intention to adopt and the actual final system use [13]. In diffusion of innovations, the perceived benefits and barriers of costs are usually the determined indicators for the technology adoption [17]. Thus, potential users' attitudes and perceptions are critical in the promotion of smart metering. The public participation of smart metering can be improved through strengthening of ideological attitudes (for sustainability) and perception. The significant factors related to potential users' attributes and perceptions will inspire diffusion practices in the implementation. With a clear idea about the influential factors, the decision makers can improve public involvement in smart metering.

4. PRIORITIES IN SMART METERING IMPLEMENTATION

4.1 Time-of-Use

In the empirical research of Backlund et al., energy management practice combined with energy efficiency technology is a cost-effective way to improve energy efficiency [18]. In addition to the diffusion of energy efficient technologies, an effective management practice is the policy instrument of pricing, for example, by moderating the fluctuating prices of energy. Accompanied by smart metering, Time-of-Use (ToU) pricing policy is an effective and an existing policy instrument tailored to electricity consumption. The real-time data acquisition of smart metering is an important technique to support the ToU tariff. Smart metering enables switching and transmitting the expenditure information directly to the energy users. The consumers can enjoy discount prices of energy through switching their on-peak consumption to mid-peak or off-peak as far as possible.

ToU pricing policy effects the diffusion of smart metering through consumers' perceived benefits. If ToU tariff was applicable, smart metering will serve to reduce the consumers' energy bills. Meanwhile it will also reduce the power demand overburden of the supplier companies during the on-peak period. In reality, the tariff in some cities, for instance Hong Kong, is relatively low [19]. The power consumption accounts for a relatively low proportion of daily expenses. Thus, it is speculated that ToU tariff may not receive adequate attention. However, with the intuitive interpretations of perceived benefits, such as bill cutting, many cities, such as London, Sydney and New York, still advocate the ToU pricing policy. Launching ToU tariff with smart metering projects would be an effective practice for diffusion from the successful experiences in many countries.

4.2 Cost-benefit Analysis

The presumed savings of energy efficiency investment are usually not achieved [20]. Investment for energy efficiency is often taken for granted due to the necessity of sustainable development. The increasing investment of smart metering is being made progressively, but whether smart metering is worthwhile has caused massive debate. Besides smart meter projects mostly relying upon the government to take the lead in promotion, a proper appraisal of the projects needs to be made for accountability purpose. The projects need to be cost-effective upon assessment. Cost-benefit Analysis (CBA) is a regular analytical method helping with decision-making in environmental arena [21]. Various costs and benefits should be evaluated in the overall projects' assessment. CBA can serve as a useful decision-making tool before the gradual diffusion of smart metering.

Although government agencies demonstrate the commitment, subsidies and incentives to launch smart meter projects in Canada, they were still challenged because of lacking CBA [22]. In contrast, a comprehensive CBA study has been carried for smart metering in the UK, but the project still needs improvement because the roll-out is at risk of schedule delays [8]. Diffusion is one of the most critical problems in the roll-out of smart meters. Because of the delays of the installation schedule, costs of the smart metering may be increased by a large amount. Besides, with the advent and update of new technologies, the obsolete first-generation smart meters seems to be squandering taxpayers' dollars. Thus, before the implementation stage, the variety of benefits and costs of smart metering needs be demonstrated to establish a more comprehensive CBA for realistic decision-making, especially in light of the generational diffusion. In this connection, the evaluation of net present value should take consideration of an appropriate discounting rate in line with the life cycle of smart meters.

4.3 Non-market Benefits

Market and non-market failures were considered to account for the limited cost-effectiveness of energy-efficiency technology [23]. Both the benefits and costs of smart metering adoption can be monetary or non-monetary. The expected returns of smart metering are generated from the consumer, supplier, network, load-shifting, carbon reduction, and other non-quantified benefits. The indirect effects of energy conservation and environmental friendliness should also be identified and quantified. Another criticism about smart metering is that the benefits which were expected in the CBA may not be fully achieved [8]. BEIS showed that the average reduction of energy consumption was just around 2.8% for electricity in the UK [24]. More benefits may come from the non-market part.

The non-quantified benefits as perceived by the users, such as health, environmental friendliness and happiness, are usually overlooked. The direct and indirect non-market benefits together with energy-savings should be evaluated clearly and presented to the public. In the project assessment, the market and non-market values will both effect the results of cost and benefit analysis of smart metering. Since the direct energy-saving will be calculated directly with the market pricing, other approaches for quantifying intangible costs and benefits should be used. The Contingent Valuation method is one of the basic variants of stated preference methods suitable for the intangible benefits valuation [21]. A full and complete CBA transparent to the public can accelerate the diffusion of smart metering. A clear understanding of the benefits ensures that the public put less pressure on the smart metering project implementation. Thus, through clarifying non-market benefits, the potential users' attitudes towards smart metering may be improved, which helps with the diffusion.

4.4 Renewable Energy Generation

With the shortage of fossil fuels and the pollution on the environment through the burning of coal, people are increasingly concerned about the development and utilization of new energy sources. Technologies with emission reduction capabilities are already commercially available. Renewable energy generation and policy measures (e.g., Feed-in-Tariff or Renewable Energy Portfolio) will enhance the energy efficiency. The renewable energy incentives have been put into place in many countries. Taking Hong Kong, for example, a small amount of renewable energy is produced as indigenous production, which currently accounts for roughly 0.1% of the total electricity consumption, with an aim to achieve a 3-4% in the longer run [25]. Thus, the function of renewable energy's generation should be included in the smart metering. The original benefits will be increased with the additional benefits of the renewable energy. The increased understanding of benefits may be brought about through public engagement in the smart metering campaigns. The utility companies should commit to promote an increased use of renewable energy technologies whilst spearheading with smart meters.

5. CONCLUSION

This research tries to inspire a clear recognition on smart metering diffusion to help the decision makers to learn from others' experiences. As a nearly real-time information system in smart city development, potential usage demand of smart metering may be predicted with the Bass Model to help with estimation. Summarizing from a series of technology diffusion models, the attitudes and perception of potential users may be identified as critical parameters to promote the adoption of smart metering. Based on this approach, four priorities to improve implementation were derived with the experiences of different countries. ToU tariff is a useful pricing policy to enhance the consumers' perceived benefits with intuitive interpretations of bill cutting. In addition, a more comprehensive CBA for decision-making needs to be demonstrated in the implementation of smart metering, especially in establishing a realistic picture of generational diffusion. Besides, a comprehensive non-market benefit estimation would ensure the public's understanding of the diffusion process clearly, which helps to alleviate some of the public criticisms and put less pressure on the smart metering project implementation. Further, the renewable energy generation and policy measures as the incentives will increase the benefits of smart metering to help with the diffusion. Hence, the prediction of future adoption would inform an appropriate direction of promotion to help the smart metering diffusion achieve a better result.

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