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Allowance trading and energy consumption under a personal carbon trading scheme: a dynamic programming approach

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ABSTRACT

In response to the challenge of climate change, personal carbon trading was put forward as a policy instrument to promote low carbon behavior in the household sector. To evaluate the effectiveness of this scheme, it is important to gain insight into the allowance trading and energy consumption behavior in a long emission commitment period. This paper proposes a dynamic programming model to investigate allowance trading and energy consumption. A main feature of the model is its consideration of allowance banking and borrowing activities. Ten simulated scenarios with different allowance prices, price volatility and carbon emission rates are discussed. The findings show that consumers would trade more actively when allowance price is volatile. It is also found that energy consumption and allowance trading will decrease when the carbon emission rate increases. Overall the analysis in this paper implies that personal carbon trading scheme would be an effective policy measure to change consumers' behavior. Therefore it would be valuable for decision-makers to consider the introduction and implementation of this scheme.

1. Introduction

Global carbon emission is increasing rapidly. If this trend continues, it will bring about disastrous climate changes. As the world's largest CO_2 emitter, China is facing great pressure to reduce its carbon emissions. Current efforts to reduce carbon emissions largely rely upon promoting energy efficiency and renewable energy consumption in upstream production sectors (Brauneis et al., 2013). For instance the Chinese government shut down many carbon-intensive assembly lines and launched subsidy programs for renewable energy production and consumption (Yuan and Xu, 2011). Some climate exchanges such as the Tianjin Climate Exchange and Beijing Environmental Exchange have been established as market-based mechanisms to curb carbon emissions.

However these initiatives have not delivered the scale of carbon reduction as required (Seyfang, 2007). Improving energy efficiency lowers the implicit price of energy and thus may lead to greater use. This phenomenon is termed the “rebound” effect in the literature (Herring, 2006). As a result the carbon abatement effect of improving energy-efficiency has been offset by the increase of household energy consumption (Lenzen and Murray, 2001). Therefore sustainable development can only be achieved by radical changes of lifestyle and residential consumption behavior (Rood et al., 2003; Fan et al., 2012). In China the household sector is currently the second-largest energy consumer, accounting for 11% of total energy consumption in 2012, and just trailing the industrial sector (National Bureau of Statistics of China, 2014). If some measures are taken to change the consumption patterns and improve energy use efficiency, the household sector could achieve the aim of approximately 28% carbon reduction by 2020 (Murata et al., 2008). Thus, to engage consumers and households directly, new policies are needed so as to induce behavioral changes and establish sustainable lifestyles (Nissinen et al., in press).

Personal carbon trading (PCT) could be an effective way to achieve sustained reductions at the household level by using carbon rationing and allowance trading. It would be a downstream extension of the “cap and trade” emissions trading scheme, and hence could result in widespread behavioral changes in reducing carbon footprints (Harwatt et al., 2011). The PCT scheme allocates consumers free emission allowances which would be reduced over time (Harwatt et al., 2011). Under-emitters with carbon emissions less than the allowance allocation could sell their surplus allowances for profit. Over-emitters who emit more than their allowance allocation have to buy additional allowances (Cohen, 2011). The

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technologies needed for the implementation of a PCT scheme, such as personal electronic cards, banking system and so on, are already available now. These would lay the bedrock for the social acceptability of PCT.

The effect of a PCT scheme on consumers' energy consumption behavior has attracted a lot of attention in the literature (Capstick and Lewis, 2010). Some authors argued that the PCT scheme would make consumers more aware of their personal emissions and help them to be engaged in emission reduction and to share a wider common purpose (Fleming, 2005; Starkey and Anderson, 2005). Others suggest that the PCT scheme would promote carbon budgeting (Capstick and Lewis, 2008; Howell, 2012). The PCT mechanism would lead to consumers' conservation of their carbon allowances and thus a reduction in carbon-related consumption (Parag and Strickland, 2009). Most of the existing studies are exploratory and logically inferred. Recently several empirical studies investigated the effect of the PCT scheme on consumers' behavior. Capstick and Lewis (2010) used computer-based simulations to examine the effects of consumers' decisions on their allowance trading and energy consumption behavior. Harwatt et al. (2011) used bespoke software to record consumers' behavioral responses and found that the PCT scheme would achieve behavioral changes in energy consumption.

However mathematical modeling of the PCT scheme is limited. Li et al. (2014) and Fan et al. (2015a,b) constructed the optimization models of the PCT scheme to investigate consumers' energy-use choice and allowance trading behavior. These studies however ignored allowance banking and borrowing activities which could smooth the marginal abatement cost across years (Parsons et al., 2009). According to Raux (2010), the PCT scheme is a part of a wider instrument, namely transferable permits. Consumers are allowed to transfer these permit quotas between activities, products or places (offsetting), periods of time (banking) or to others (Godard, 2001). It is argued that intra-phase banking and borrowing is able to stabilize the allowance price level in the upstream emission trading system (Carmona et al., 2010). The present study attempts to fill the gap in the PCT literature and investigate the consumers' sequential behavior in energy consumption and allowance trading by taking inter-stage banking and borrowing into consideration. Specifically, stable and volatile allowance price scenarios are simulated to analyze their influences on consumers' decision-making.

The rest of the paper begins with a review of the related literature. Subsequently a dynamic programming (DP) model of the PCT scheme is proposed. Then the simulations are conducted to investigate consumers' energy consumption and allowance trading behavior under different scenarios of allowance prices or emission rates and the results are discussed. The final section concludes the study and provides policy implications and recommendations for future research.

2. Literature review

The PCT scheme, a radical idea, was developed and promoted by two independent researchers in the mid-1990s (Fleming, 1997; Hillman, 1998). Academic passion for PCT has since never faded. Researchers have investigated the equity, public acceptability, distributional effects, and behavior changes associated with this scheme. For instance, Wallace et al. (2010) investigated public attitudes toward a PCT scheme and found that support outweighs opposition. Wadud et al. (2008) conducted an equity analysis of a PCT scheme for road transportation sector and concluded that, overall, the PCT scheme is progressive among consumers on an equal allocation basis.

Several authors analyzed the influence of PCT on consumers' energy consumption behavior. Roberts and Thumim (2006) suggested that PCT could bring about behavioral changes in energy consumption at the individual and household level. Capstick and Lewis (2008) indicated that consumers' energy-related consumption behaviors are influenced through heightened recognition of consequences and the accentuation of energy consciousness. Wallace (2009) used face–face interviews and the postal survey method to examine the consumers' behavioral responses to the PCT scheme and reached a conclusion that several low-carbon behaviors are favored by households. Zanni et al. (2013) conducted an experimental survey to explore individual behavioral responses to PCT in contrast with a carbon tax and showed that a PCT scheme would affect personal transport and domestic energy choices. Raux et al. (2015) used a stated preference survey and argued that a PCT scheme would effectively change consumers' travel behavior. Most of these studies provide the evidence of the effectiveness of the PCT scheme empirically or in an exploratory way from a psychological perspective.

Given the novelty of the PCT scheme, only a few researches have begun to model and investigate consumers' behavioral changes from an economic perspective. Li et al. (2014) proposed an equilibrium model for the PCT and investigated consumers' welfare change. Fan et al. (2015a) extended this equilibrium model to analyze consumers' energy-choice consumption and allowance trading which are subjected to the influence by factors such as allowance allocation and carbon emission rate. In another study, Fan et al. (2015b) employed an optimization model to investigate the consumers' energy demand and concluded that the PCT scheme is capable of providing certainty in carbon abatement. However these studies model the PCT scheme from a static view and ignore the fact that allowances could be transferred from one period to another (Parsons et al., 2009).

Furthermore allowance price, its volatility and carbon emission rates should be considered in consumers' decision processes. Price volatility has significant influences on consumers' trading behavior (Bessembinder and Seguin, 1992). Fawcett (2010) suggested that in a PCT scheme an equilibrium allowance price would emerge and that higher carbon lifestyles would cost more. McNamara and Caulfield (2013) examined the impact of different allowance prices under a PCT scheme in the field of the transport sector and found that consumers with sustainable lifestyles would benefit more from the higher allowance price. These studies indicated that the allowance price would provide signals and incentives for consumers' lifestyle transition. Li et al. (2014) and Fan et al. (2015a) developed optimization models and investigated how the allowance price is determined and how it would influence consumers' energy consumption and allowance trading. These studies assume that equilibrium allowance price is endogenous in the long run. The present research is complementary to the existing studies by assuming that the consumer is a price-taker in the short run.

The carbon emission rate is another factor which influences the decision-making of firms and consumers under the constraints of carbon emission. Fan et al. (2015a) found that allowance trading volume would be susceptible to the changes in the emission rate. When the emission rate decreases, the equilibrium allowance price would decrease and the allowance trading volume would increase. Fan et al. (2015a) however mainly considered the influence of the emission rate on the total allowance trading volume in the thick market. The present research attempts to further investigate the influence of emission rate on consumers' energy consumption. It adopts the DP approach to investigate the consumers' decision-making process for energy consumption and allowance trading by taking into consideration of “banking and