

ECONOMICS

THE EFFECTS OF ALLOWANCE PRICE ON ENERGY DEMAND UNDER A PERSONAL CARBON TRADING SCHEME

by

**Jin Fan,
Jun Li**

**School of Management, University of Science and
Technology of China**

**Yanrui Wu
Business School
University of Western Australia**

and

**Shanyong Wang,
Dingtao Zhao
School of Management, University of Science and
Technology of China**

DISCUSSION PAPER 16.07

THE EFFECTS OF ALLOWANCE PRICE ON ENERGY DEMAND UNDER A PERSONAL CARBON TRADING SCHEME

Jin Fan^a, Jun Li^a, Yanrui Wu^b, Shanyong Wang^a, Dingtao Zhao^a

^aSchool of Management, University of Science and Technology of China, P.R. China

^bBusiness School, University of Western Australia, Australia (Corresponding author:

yanrui.wu@uwa.edu.au)

Forthcoming in *Applied Energy* (JIF: 5.513)

DISCUSSION PAPER 16.07

Abstract: Personal carbon trading (PCT) is a downstream cap-and-trade scheme which could be used to reduce carbon emissions from the household sector. To explore the effectiveness of this scheme, it is necessary to investigate how consumers respond to allowance price change.. In this paper, a general utility optimization (GUO) model and a constant elasticity of substitution (CES) utility function are proposed to examine the price, substitution and income effects of carbon allowance price changes. It is shown that higher income consumers are more sensitive to the allowance price changes than lower income consumers. Moreover, the short-run adjustment in consumers' consumption of electricity in response to a change in allowance price would be lower than the long-run value. According to the sensitivity analysis, downward (upward) adjustments in the elasticity of substitution result in a positive (negative) effect on price effect. The findings in this study are used to draw policy implications. Suggestions for future research are also provided.

Keywords: Energy; Personal carbon trading; Allowance price; Income effect; Substitution effect (**JEL codes:** Q52, Q56, Q58)

1. Introduction

Carbon emissions caused by the energy consumption of households have become a significant source of total emissions and have attracted widespread attention from scholars and government agencies [1, 2]. For instance, according to Reinders et al.[3] the proportion of direct energy (electricity, coal, gasoline, etc.) consumption by the households accounts for the total energy demand in different EU countries varies from 34% to 64%. In China, about 30% of carbon emissions are generated by households' energy consumption [4]. Moreover, due to the increase in disposable income, population growth, mobility, urbanization, and growing penetration of energy intensive appliances in households, households' energy consumption and associated carbon emissions will continue to grow rapidly [5-7]. Thus, to avoid catastrophic climate change, changes in consumer behavior are generally considered to be an option for CO₂ reduction [3]. These changes are essential to build awareness of sustainable lifestyles and the synergies between policy, technology, and ethical imperatives. It is expected that sustainable lifestyles, as one of the carbon mitigation measures, would contribute to carbon reduction and mitigate climate change.

Personal carbon trading (PCT) has been generally regarded as a potentially powerful and innovative policy instrument to reduce carbon emissions at the individual and household level and promote low-carbon lifestyles. The concept of PCT was first proposed by Fleming in 1996 [8]. In recent years, at national government level, it has aroused great interest and considerable discussion in the UK where government aims to achieve a legally binding emissions reduction target of an 80% cut by 2050 relative to the 1990 level

[9]. PCT is usually seen as a variety of the downstream “cap and trade” policies that allocate rights and responsibilities for carbon emissions from the household energy use. In a PCT scheme, each consumer would be allocated with an initial allocation of carbon allowances based on carbon reduction targets, which could be used alongside traditional money, to cover the consumer’s emissions associated with the consumption of energy commodities, such as gas, coal, electricity and so on. Such allowances could also be traded between consumers. The over-emitters who emit more than their initial allowances have to buy extra allowances from the under-emitters who emit less than their allowances allocated. The demand and supply of allowances, which would be influenced by initial allowance allocation, energy emission rate, energy price and so on, will determine their price [10].

As a market-based approach to internalize environmental externalities at the level of personal emissions, PCT scheme provides a pricing mechanism for carbon emissions and a market for trading allowances. Specifically, allowance price enhances the cost of a high-carbon lifestyle and can pass through a more direct signal to reduce carbon emissions. The higher the allowance price, the more the consumers would be willing to shift from carbon intensive energies to less carbon intensive ones [11, 12]. Therefore, the carbon allowance price plays a critical role to affect consumers’ consumption decision making, especially the decision of energy consumption.

Considering the importance of the allowance price, it is essential to explore its effect on consumers’ energy demand which reflects the effectiveness and efficiency of the PCT scheme to reduce carbon emission. In a PCT scheme, carbon allowances could be viewed

as a form of complementary currency (CC) which could be used to solve some environmental problems that conventional currency cannot address directly [13]. Since allowances and energy can be treated as complementary goods, the allowances could be used either for supporting energy consumption or for being exchanged for money to generate a benefit [14]. When allowance price changes, the opportunity cost of selling allowances and the purchasing cost of energy consumption will change. Because of the heterogeneity of consumers, different consumers may have different responses to allowance price change in different periods.

However, these arguments are based on qualitative judgments rather than quantitative analyses. There is little research on how allowance price affects personal energy demand of different consumers. This study attempts to fill the void in the literature. The remainder of the paper is organized as follows. Section 2 provides a literature review. Section 3 introduces a theoretical model to obtain the formulae of the price effect, substitution effect and income effect under the PCT scheme. Section 4 evaluates the parameters of the model. Sections 5 and 6 present the results, discussion and sensitivity analysis. Finally section 7 concludes the paper and points out the implication and limitations of the results.

2. Literature Review

The potential for the introduction of PCT at individual or household level has attracted much attention in both academic research and policy making. Specifically, in 2010, the *Climate Policy* journal devoted a special issue to PCT scheme with ten articles. Most studies focused on scheme design, implementation, distributional effects, its

comparison with other emission reduction instruments such as carbon tax (CT) and upstream trading scheme [9, 15-18].

Under a PCT scheme, a key issue discussed by researchers is how the initial allowance allocation to consumers is carried out [17]. There are two basic choices for supplying initial allowance to individuals or households. The first choice is that allowances are allocated for free and the second one is that allowances would be auctioned. From the perspective of economic efficiency, it is often deemed to be more efficient if initial allowances are auctioned, rather than issued free of charge [19]. Many researchers however believed that the problems of political and social acceptability would be minimized through the way of free allocation of allowances, because it allows individuals or households to consume a certain amount of energy without bringing about any additional cost. Generally speaking, PCT is based on the egalitarian principle of equity [20], which is inspired by the international carbon reduction proposal of ‘contraction and convergence’, that is, everyone has an equal right to emit greenhouse gases [21]. Current studies on PCT were mainly based on the assumption of equal per capita or household allocation (usually free) as their analytical starting point. In this paper, we adopt the same assumption.

Some authors have compared PCT with the existing policy instruments in practice, such as carbon taxes and upstream trading schemes [22]. Weitzman [23] argues that taxes and tradable permits are theoretically equivalent in terms of efficiency and effectiveness. However, a carbon tax policy is a price-based environmental regulation which fixes the allowance price and lets the market determine the amount of carbon emissions emitted,

while a PCT scheme is mainly a quantity-based instrument which fixes the quantity emitted and lets the allowance price be determined by the market. It is argued that, if there is uncertainty over the cost function, it is better to fix the price through a tax policy, and if there is uncertainty over the damage function, fixing the quantity through a trading system is more appropriate [24, 25]. In the context of climate change, the damage function is uncertain due to the time lag between emissions and their effect on the environment, and potentially catastrophic impacts of missing abatement targets [17].

One of the merits of price based regulation, such as the carbon tax, is the simplicity and ease of implementation and administration [26]. A government can directly set the level of a tax, while it cannot set in advance the allowance price in a PCT scheme. The price signal of carbon taxes is certain, and the price response function of consumers associated with the amount of reductions is determined by the elasticity of energy demand. According to the price elasticity of energy demand¹, carbon tax can be designed to obtain significant reductions in carbon emissions from the residential sector [26]. However, the tax rate is the same for all consumers. Therefore, this scheme is regressive because lower income households are paying proportionately more than higher income households [27]. In contrast, the PCT scheme which combines economic incentives and quantity control is believed to be progressive [28]. In a PCT scheme, everyone could obtain a certain amount of equal allocation of allowance free of charge, which represents the characteristic feature of equity [29]. Some have argued further that, since low-income consumers tend to emit less carbon than high-income ones, low-income consumers could obtain extra income by

¹ Price elasticity values vary between -0.3 for the short-term and -0.7 for the long-term [28].

selling their unwanted carbon rights to those more wealthy in the market [19].

When comparing upstream trading scheme with downstream trading scheme, it is common to discuss the difference between them. Upstream trading schemes could be more transparent, simpler, cheaper, and quicker to implement in practice [30]. In an upstream trading scheme, the allowances are allocated to fuel suppliers and importers [31]. Nowadays, the world's biggest upstream emission trading scheme is European Union emission trading scheme (EU ETS), which covers emissions from energy-intensive industries [32]. Under this scheme, the cost of purchasing allowance will affect the cost of energy or some other goods supplied to consumers. Companies will seek to pass-through this cost to the consumers by building it into fuel price [31, 32]. Moreover, many studies show that the effective pass-through rate of carbon cost is determined by the elasticities of demand and supply [33, 34]. PCT could be regarded as a market-based approach to curb carbon emissions, which combines the economic incentives and quantity control. First, the allowance price provides a direct price signal and economic incentive for consumers to change their high-carbon consumption behaviors, though the price signal is unknown and might be weak or null [35]. Second, the allowance constraints under a PCT scheme offer certainty about the goals of carbon abatement, which are uncertain under a carbon tax policy. In addition, PCT would provide an incentive for people to cooperate and collaborate with others to achieve shared reduction goals, under which people would become more aware of their personal emissions and more prone to considering ways to reduce their emissions [13].

In existing studies, few researchers have investigated consumers' behavioural

response to PCT, especially the response to allowance price change. Only a few studies explore this issue from the perspective of public acceptability [36-38]. To explore the effectiveness and efficiency of the PCT scheme to reduce carbon emission, it is necessary to investigate how consumers' response to allowance price changes. This study employs a general utility optimization (GUO) model and a generalized constant elasticity of substitution (CES) utility function to examine the price, substitution and income effects of allowance price. It takes into account of several factors such as initial allowance allocation, energy emission rate, energy price, and income budget. These factors are important determinants of implementing a PCT scheme.

3. Methods

A PCT scheme incorporates energy consumption choices into a decision-making frame [19]. This decision-making process can be framed as a budgeting process which may encourage self-control over one's carbon emissions through basic economic mechanisms [39]. It is reasonable to assume that consumers allocate expenditure between energy goods and non-energy goods [40]. The model is based on the theory of consumer choice behavior which assumes that a rational consumer always chooses consumption bundles to maximize utility subject to budget constraints. Table 1 shows nomenclature for the mathematical symbols used in this study.

Table 1 Summary of the mathematical symbols

Symbol	Description
I	Income budget
p	Energy price vector
q	Non-energy commodity price vector
p_c	Allowance price
x	Energy consumption vector
y	Non-energy consumption vector
c	Energy emission rate vector
ψ	Carbon allowance quantity traded
ω	Initial allowance allocation
α and β	Exponents of utility function and $\alpha + \beta = 1$
$x_i(\cdot)$	Marshallian demand function
$h_i(\cdot)$	Hicksian demand function
P	Total price vector
Y	Total income budget
$v(\cdot)$	Indirect utility function
PE	Allowance price effect on energy demand
SE	Substitution effect
IE	Income effect

3.1. A GUO model under the PCT scheme

For simplicity, the consumption bundle is assumed to consist of two categories, namely, energy goods x and non-energy goods y . In a PCT scheme, a consumer not only

must pay money, but also needs to pay or surrender certain carbon allowances when the consumer purchases energy. Thus, the consumer's utility optimization is subjected to two constraints, namely, income budget and initial carbon allowance. Assume the consumer under the scheme is a price-taker. The consumer's optimal choice behavior can be captured by the following utility maximization problem:

$$\begin{aligned} \max u &= u(x, y) \\ \text{s.t.} &\begin{cases} px + qy + p_c \psi \leq I \\ cx - \psi \leq \omega \end{cases} \end{aligned} \quad (1)$$

where $u(x, y)$ represents the consumer's general utility function, $x = (x_1, x_2, \dots, x_m)'$ is an energy consumption vector, $y = (y_1, y_2, \dots, y_n)'$ is a non-energy consumption vector, I is the income budget, $p = (p_1, p_2, \dots, p_m)$ is an energy price vector, $q = (q_1, q_2, \dots, q_n)$ is the non-energy commodity price vector, p_c is the allowance price, $c = (c_1, c_2, \dots, c_m)$ is the energy emission rate vector, and ψ is the carbon allowance quantity traded. If $\psi > 0$, the consumer is an over-emitter who needs to purchase allowances. Conversely, if $\psi < 0$, the consumer is an under-emitter and can sell surplus allowances to obtain extra incomes. ω is the initial allowance allocated for each consumer.

The constraint conditions of equation (1) imply

$$(p + p_c c)x + qy \leq I + p_c \omega \quad (2)$$

Let $P = p + p_c c$ and $Y = I + p_c \omega$, then equation (2) can be expressed as

$$Px + qy \leq Y \quad (3)$$

where $P = (p_1 + p_c c_1, p_2 + p_c c_2, \dots, p_m + p_c c_m)$ is the total price vector and Y is the total income budget. Equation (3) is defined as the total income budget constraint.

Define the indirect utility function $v(P, q, Y)$ as the highest level of utility the

consumer could reach given prices P , q and budget Y [41, 42]. Then

$$\frac{\partial v(P, q, Y)}{\partial p_c} = \sum_{i=1}^m \frac{\partial v}{\partial P_i} \frac{\partial P_i}{\partial p_c} + \frac{\partial v}{\partial Y} \frac{\partial Y}{\partial p_c} \quad (4)$$

Roy's identity implies [35]

$$\frac{\partial v}{\partial P_i} = -v_Y x_i \quad (5)$$

Thus, through the manipulation of equations (1) and (3), the following identity is obtained

$$\frac{\partial v(P, q, Y)}{\partial p_c} = -\sum_i^m v_Y x_i c_i + v_Y \omega = -v_Y \psi \quad (6)$$

The duality theorem implies [42]

$$x_i(P, q, Y) = h_i(P, v(P, q, Y)) \quad (7)$$

where $x_i(P, q, Y)$ is the Marshallian demand function, and $h_i(P, v(P, q, Y))$ is the Hicksian demand function.

The partial derivatives of equation (7) with respect to Y and p_c are presented as follows

$$x_{iY}(P, q, Y) = h_{iv} v_Y \quad (8)$$

Computing the partial derivative of x_i with respect to p_c , we have

$$\frac{\partial x_i(P, q, Y)}{\partial p_c} = \sum_j \frac{\partial h_i}{\partial P_j} \frac{\partial P_j}{\partial p_c} + \frac{\partial h_i}{\partial v} \frac{\partial v}{\partial p_c} = \sum_j h_{ij} c_j + h_{iv} \frac{\partial v}{\partial p_c} \quad (9)$$

Substituting equations (6) and (8) into equation (9) to obtain

$$\frac{\partial x_i(P, q, Y)}{\partial p_c} = \sum_j h_{ij} c_j - x_{iY}(P, q, Y) \psi \quad (10)$$

According to the consumer behavior theory [42], it can be concluded that equation (10) is the Slutsky decomposition of allowance price effect (PE) on energy demand. The

substitution effect (SE) and income effect (IE) can be represented as

$$SE = \sum_j h_{ij} c_j \quad (11)$$

$$IE = -x_{iY}(P, q, Y)\psi \quad (12)$$

3.2. A specific utility function model of GUO model

In this section, a generalized constant elasticity of substitution (CES) utility function is employed to obtain the specific formulae for the price effect, substitution effect and income effect of allowance price on energy demand. The input factors in our model are of two types, namely, energy commodities x and non-energy commodities y . The CES utility function, which is homothetic, provides a quantitative illustration of the relationship between energy commodities and non-energy commodities, and how consumers react to changes in allowance price [43]. Consider a static, closed economy with a representative agent, the utility function can be written as:

$$U(x, y) = [\alpha x^\rho + (1 - \alpha)y^\rho]^{\frac{1}{\rho}} \quad (13)$$

where α expresses the weight on the payoff to energy commodities, ρ is substitution parameter which determines the elasticity of substitution σ through the relation: $\sigma = 1/(1 - \rho)$. As the values of the parameters α and ρ change, the CES utility function spans a wide range of social preferences. According to the economic literatures, the value of σ will not be negative because of the convexity of the indifference curves [44]. As ρ varies from one to negative infinity, there will be three special cases of the generalized utility function: perfect substitute utility function ($\rho = 1$), Cobb-Douglas utility function ($\rho \rightarrow 0$) and perfect complement utility function ($\rho \rightarrow -\infty$). The constraints in this CES utility function under PCT scheme are similar to those in the

general model. Thus, the consumer's utility maximization problem can be transformed into the following canonical form:

$$\begin{aligned} \text{Max} U(x, y) &= [\alpha x^\rho + (1-\alpha)y^\rho]^{\frac{1}{\rho}} \\ \text{s.t.} \left\{ \begin{array}{l} px + qy + p_c \psi \leq I \text{ (shadow price } \partial_1 \text{)} \\ c_x x - \psi - \omega \leq 0 \text{ (shadow price } \partial_2 \text{)} \end{array} \right. \end{aligned} \quad (14)$$

where p is the energy commodity price, q is the non-energy commodity price, p_c is the allowance price, c_x is the energy emission rate, I is the income budget, ψ is the carbon allowance quantity traded, and ω is the initial allowance allocated for each consumer.

The shadow prices ∂_1 and ∂_2 are defined as the marginal changes in the objective function with respect to an increase in the right-hand side of the constraint conditions. According to Hobbs et al. [45], the constraints in equation (14) imply that the shadow prices are positive. Solving the problem in equation (14) involves a linear program whose Karush-Kuhn-Tucker (KKT) optimality conditions are shown in Appendix A.

3.2.1. Substitution effect

According to equations (11) and (B8), the following formulae is obtained

$$SE_x = h_{ii} c_i = \frac{1}{\rho-1} \alpha q U P^{-2} \frac{\left[\frac{\alpha q}{(1-\alpha)P} \right]^{\frac{1}{\rho-1}}}{\left[(1-\alpha) \left[\frac{\alpha q}{(1-\alpha)P} \right]^{\frac{\rho}{\rho-1}} + \alpha \right]^{\frac{1+\rho}{\rho}}} c_x \quad (14)$$

where U is the minimum utility level required by the consumer (see Appendices A and B for the detailed derivation process).

Since the value of the elasticity of substitution σ will not be negative, the symbol of $1/(\rho-1)$ will be negative. Thus, Equation (14) implies that the substitution effect of

allowance price on energy demand is always negative. This is consistent with the traditional economic theory of consumer choice [46]. Koutsoyannis [47] argues that the negative substitution effect is an inevitable consequence of the “preference hypothesis”. The logic is that a price increase of one good alters the relative prices and induces substitution of the relatively cheaper good for the relatively more expensive good. In a PCT scheme, when the allowance price rises, the total price of energy will also rise, and hence the substitution effect will be negative for all consumers, namely, both the over-emitter and the under-emitter.

3.2.2. Income effect

However, the income effects for the under-emitter and the over-emitter will be different. Equations (12) and (A15) imply

$$IE_x = -x_{iy}(P, q, Y)\psi = -\frac{K}{1 + KP}\psi \quad (15)$$

where K is equal to $(\frac{1-\alpha}{\alpha} \frac{P}{q})^{\frac{1}{\rho-1}} \frac{1}{q}$, and ψ is equal to $KYc_x / (1 + KP) - \omega$.

Thus if $\psi > 0$ or the consumer is an over-emitter, the income effect is negative, and then the total price effect is negative. That is, the energy demanded by the over-emitter will always decrease when the allowance price increases. The over-emitter should purchase additional allowance to maintain a high-carbon lifestyle. When the allowance price rises, the consumer’s real income will decrease and thus the income effect will be negative.

However, if $\psi < 0$ or the consumer is an under-emitter, the income effect is positive. The under-emitter could sell surplus allowances to gain extra income. When the allowance price increases, the income obtained through the sale of surplus allowances will rise and

thus the income effect will be positive. Therefore, the influence of allowance price on energy demand will be determined by the negative substitution effect and the positive income effect jointly.

4. Simulation

To explore how different consumers react to a PCT scheme and try to manage it differently, in this section, we will utilize electricity consumption statistics to estimate the parameters of our CES utility model if a PCT scheme is introduced in the US residential sector. In the U.S., the residential sector accounts for 37 percent of national electricity consumption and 17 percent of carbon dioxide emissions [48]. For simplicity, it is assumed that the PCT scheme only covers the household electricity consumption in the simulation analysis.

For the simulation analysis, the parameters in the model are assessed as follows. The average household income in several percentile groups is obtained from the US Census Bureau [49] (see Table 3). Since the electricity charge is calculated according to the family unit not the number of members in the family, the average household income can be used to represent I defined in equation (1). According to 2013 OECD data reported by IEA [50], the average emission rate of electricity c_x was 0.48 kg/kWh² and the electricity price p in the residential market was \$0.12/kWh.

² The renewable electricity is taken into account.

Table 3 Distribution of American Household Income in 2013

Percentile	Average Household Income in U.S. (\$)
Lowest 20%	11,544
21%-40%	30,919
41%-60%	52,717
61%-80%	83,937
81%-100%	189,718
Top 5%	339,950

Source: US Census Bureau.

The appropriate allocation of carbon allowances is critical for the allowance market, where too high or low an allocation of initial allowances would cause market failure [10]. In order to set an appropriate level of initial carbon allowances, we will allocate an equal allowance to each household based on current electricity consumption [51]. The U.S. Department of Energy's Energy Information Administration (EIA) reports annual electricity consumption per-household of 10,808 kWh in 2005 [52].³ At the Copenhagen climate meeting in December 2009, President Obama pledged the United States emissions reduction in the range of 17 percent below the 2005 level by 2020 [53]. To meet this carbon emission reduction target, the average annual emission reduction rate should be about 1.3 percent. If this emission reduction target is met, household emissions from electricity consumption would be 4648 kg in 2013. For the purpose of simulation, it is assumed that the initial allowance allocation is $\omega = 4,648$ kg.

³ The U.S. Energy Information Administration periodically publishes the Residential Energy Consumption Survey (RECS), a national area-probability sample survey that collects residential energy-related data, available at http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_1.

Varian [54] uses three different techniques to estimate the parameters of a utility function. In this study, the average expenditure share of each good is used to estimate the parameter α . Since the parameter α in the simulation analysis represents the commodity share of electricity x in total expenditure, the parameter can be estimated as follows

$$\alpha = \frac{1}{n-k} \sum_{t=k}^n \frac{p_{xt} \cdot x_t}{Te_t}, \beta = 1 - \alpha \quad (16)$$

where p_{xt} is the electricity price in year t , x_t is average electricity consumption per capita in year t , Te_t is the household final consumption expenditure per capita in year t , k and n represent the start and end points of the time interval, respectively.

As shown in Table 4, the data include average electricity consumption, electricity price, and total annual expenditure from 2003 to 2012. Through calculation based on equation (18) and the data in Table 4, the value of α is 0.02. This number is close to the observed ones. The allowance price p_c is assumed to be \$0.03/kg, which is similar to the value provided by McNamara and Caulfield [16] and Brauneis et al. [55].

Table 4 The data for estimating parameters

year	x_t (kWh)	p_{xt} (\$/kWh)	Te_t (\$)
2003	4,375.28	0.09	28,191.17
2004	4,400.75	0.09	29,004.61
2005	4,576.89	0.10	29,745.88
2006	4,507.55	0.10	30,347.18
2007	4,613.91	0.11	30,734.81
2008	4,527.11	0.11	30,341.88
2009	4,430.53	0.12	29,620.24
2010	4,667.01	0.12	29,946.16
2011	4,559.67	0.12	30,468.08
2012	4,373.81	0.12	30,902.85

Source: The World Bank database and OECD database.

A key parameter that drives utility analysis under a PCT scheme is the elasticity of substitution between energy and non-energy goods in the household's CES utility function. In this study, the value of parameter σ is estimated by Lecca et al. [56] who use a conventional general maximum entropy (GME) estimation method to obtain that the short and long-run elasticity of substitution is equal to 0.35 and 0.61, respectively.

5. Results and Discussion

Given the parameters identified in section 4 and equations (14) and (15), the income effect, substitution effect and the price effect of allowance price on electricity demand in the short and long-run can be calculated. The specific results are presented in Tables 5 and 6. The allowance price effect on electricity demand in both short and long-run is negative for all households with different income. Thus, when the allowance price rises, the consumer will reduce electricity consumption. It is effective to introduce a PCT scheme for carbon emission reduction. Through a stated-preferences survey, Raux et al. [57] shows that PCT could effectively change energy consumption behavior and hence reduce carbon emissions. If this scheme is introduced, a market price for carbon allowances would emerge and high carbon lifestyles would cost more than they currently do. The market price signal could provide incentives for a transition to low-carbon lifestyles such as the purchase of clean-energy vehicles and reduction in car usage [58]. Starkey and Anderson [59] also note that if consumers are confronted with an explicit ration of carbon allowances, they would become more aware of their personal emissions and spend more time and effort considering ways to reduce their emissions.

Table 5 The effect of allowance price on electricity demand in the short-run

Scenario I		Short-run ($\sigma = 0.35$)		
percentile	<i>I</i>	<i>IE</i>	<i>SE</i>	<i>TE</i>
Lowest 20%	11,544	857.96	-6350.40	-5492.44
21%-40%	30,919	158.45	-16899.83	-16741.38
41%-60%	52,717	-628.54	-28768.44	-29396.98
61%-80%	83,937	-1755.71	-45767.12	-47522.83
81%-100%	189,718	-5574.81	-103362.78	-108937.59
Top 5%	339,950	-10998.76	-185161.11	-196159.87

Source: Authors' own calculation.

Furthermore, the results in Tables 5 and 6 show that consumers with different income levels would have different responses to allowance price change. As shown in Table 5, consumers with higher income will be more sensitive to the allowance price changes than consumers with lower income. This finding is consistent with our expectation as consumers with higher income may need more allowances to maintain their daily electricity consumption than the lower income consumers [19].

Table 6 The effect of allowance price on electricity demand in the long-run

Scenario II		Long-run ($\sigma = 0.61$)		
percentile	<i>I</i>	<i>IE</i>	<i>SE</i>	<i>TE</i>
Lowest 20%	11,544	624.48	-7329.08	-6704.60
21%-40%	30,919	361.99	-19488.67	-19126.69
41%-60%	52,717	66.66	-33168.89	-33102.23
61%-80%	83,937	-356.32	-52762.26	-53118.58
81%-100%	189,718	-1789.47	-119149.38	-120938.84
Top 5%	339,950	-3824.85	-213433.50	-217258.35

Source: Authors' own calculation.

It is important to explore the difference of consumers' response to allowance price change in different periods. As shown in Tables 5 and 6, the short-run adjustment in consumers' consumption of electricity in response to a change in allowance price would be lower than that in the long run. Two reasons could be given to explain this difference. First, there may be a degree of inertia in electricity consumption which suggests that the process of consumers' electricity consumption habit change takes time. Second, for full adjustment of their electricity consumption in response to the allowance price change, consumers may have to invest in new energy-saving durables, which only occurs in the long run.

In addition, Table 5 illustrates that for households in the lowest 20% and 21%-40% percentile their income effects are positive in the short run. According to Section 3.2.2, it is known that these households are under-emitters. Households in other groups (41%-60% , 61%-80% and 81%-100%) are over-emitters, since their income effects are negative. However, Table 6 shows that income effects are positive for households in the 20% , 21%-40% and 41%-60% percentile and negative for other households (61%-80% and 81%-100%) in the long run. Thus, the role of the households in 41%-60% percentile is different over time. This difference may be due to the improvement of energy efficiency of household appliances in the long run. The increase in energy efficiency in the long run allows consumers to obtain the same utility level by using less electricity than that required in the short run. Thereby the need of carbon allowances will decrease in the long run. Therefore, there will be more consumers transitioning from over-emitters to under-emitters in the long run, which implies that PCT would be an effective policy

instrument to guide consumers to more effective and efficient use of energy.

6. Sensitivity analysis

Table 7 Results of sensitivity analysis of the changes in the elasticity of substitution

ΔTE	$\Delta\sigma$	Short run		Long run	
		Baseline value: $\sigma = 0.35$		Baseline value: $\sigma = 0.61$	
		-20% ($\sigma=0.28$)	+20% ($\sigma=0.42$)	-20% ($\sigma=0.49$)	+20% ($\sigma=0.73$)
Percentile	ΔTE	ΔTE	ΔTE	ΔTE	
Lowest 20%	15.16%	-10.55%	4.01%	-1.33%	
21%-40%	11.38%	-7.60%	1.95%	-2.65%	
41%-60%	10.58%	-6.98%	1.49%	-2.95%	
61%-80%	10.18%	-6.66%	1.25%	-3.11%	
81%-100%	9.81%	-6.38%	1.02%	-3.25%	
Top 5%	9.69%	-6.28%	0.94%	-3.30%	

Note: $\Delta\sigma$ is the change rate of elasticity of substitution, ΔTE is the change rate of price effect.

According to the discussion in the preceding section, the adjustment range of consumers' electricity consumption in response to allowance price changes is closely related to the value of elasticity of substitution. In fact, the change of elasticity of substitution may have a significant effect on our findings. Thus, in this section, we perform a sensitivity analysis check to further explore this effect. The value of elasticity of substitution changes from -20% to +20% of the baseline values of elasticities in the short-run and long-run, respectively.

As shown in Table 7, downward adjustments in the short-run elasticity of substitution

by -20% result in an enhanced effect of price changes for all households. On the contrary, the upward adjustments in the short-run elasticity of substitution of +20% result in a reduced effect of price changes for all households. Moreover, the results of the sensitivity analysis in the long-term are similar to those in the short term. The difference is that the variation in the response to allowance price changes is different across various income groups which could be observed in Table 7. The sensitivity test indicates that when the value of elasticity of substitution is larger, the consumers' adjustment to the allowance price changes both in the short-run and long-run tends to be greater.

7. Conclusion

PCT is a new, untried policy proposal to reduce carbon emissions at the household level by using carbon rationing and tradable emission allowances. It is a downstream extension of the "cap and trade" scheme in the production sectors, with the aim to provide market signals and incentives for consumers to adapt to lower-carbon lifestyles. To explore the effectiveness of the PCT scheme, it is necessary to investigate how consumers respond to allowance price changes. This paper mainly focuses on the allowance price effects on electricity demand considering different elasticities of substitution.

First, it is shown that the allowance price effect on electricity demand is negative for all households both in the short-run and long-run. Thus, when the allowance price rises, consumers will reduce electricity consumption. It is effective to introduce a PCT scheme for carbon emission reduction. Second, it is found that consumers with different income would have different responses to allowance price changes. Consumers with higher

income would be more sensitive than consumers with lower income. Third, the short-run adjustment in consumers' consumption of electricity in response to a change in allowance price would be lower than that in the long-run. Finally, the sensitivity analysis shows that downward (upward) adjustments in the elasticity of substitution result in an enhanced (reduced) effect of price changes.

Although this study presented some interesting findings, it can be extended to accommodate a number of factors that are also likely to be important in practice. For instance, transaction costs are not included in this study. In addition this paper has ignored the banking and borrowing of allowances which may smooth the marginal cost of abatement over time. A model that allows for banking and borrowing would bring the analysis a significant step closer to the reality of implementing the PCT system.

Acknowledgements

The authors acknowledge the National Natural Science Foundation of China (71301157, 71571172 & 71473105) for generous financial support and editors of the Journal and several anonymous reviewers for constructive comments and suggestions.

Appendix A

The consumer solves the following utility maximization problem

$$\begin{aligned}
 & \text{Max} U(x, y) = [\alpha x^\rho + (1 - \alpha)y^\rho]^{\frac{1}{\rho}} \\
 & \text{s.t.} \begin{cases} px + qy + p_c \psi \leq I \text{ (shadow price } \hat{\partial}_1 \text{)} \\ c_x x - \psi - \omega \leq 0 \text{ (shadow price } \hat{\partial}_2 \text{)} \end{cases} \quad (\text{A1})
 \end{aligned}$$

Solving the linear programming problem in equation (A1) requires the following

Karush-Kuhn-Tucker (KKT) optimality conditions

$$0 \leq x \perp \alpha[\alpha x^\rho + (1-\alpha)y^\rho]^\frac{1}{\rho-1} x^{\rho-1} - \partial_1 p - \partial_2 c_x \geq 0 \quad (\text{A2})$$

$$0 \leq y \perp (1-\alpha)[\alpha x^\rho + (1-\alpha)y^\rho]^\frac{1}{\rho-1} y^{\rho-1} - \partial_1 q = 0 \geq 0 \quad (\text{A3})$$

$$0 \leq \psi \perp -\partial_1 p_c + \partial_2 \geq 0 \quad (\text{A4})$$

$$0 \leq \partial_1 \perp px + qy + p_c \psi - I \geq 0 \quad (\text{A5})$$

$$0 \leq \perp c_x x - \psi - \omega \geq 0 \quad (\text{A6})$$

where \perp indicates orthogonality between two vectors, which in this case simply expresses the complementary slackness condition in linear programming.

According to the Karush-Kuhn-Tucker (KKT) conditions we have

$$\frac{\alpha x^{\rho-1}}{(1-\alpha)y^{\rho-1}} = \frac{\partial_1 p + \partial_2 c_x}{\partial_1 q} \quad (\text{A7})$$

$$x = \frac{\psi + \omega}{c_x} \quad (\text{A8})$$

$$y = \frac{-px - p_c \psi + I}{q} \quad (\text{A9})$$

$$-p_c \partial_1 + \partial_2 = 0 \quad (\text{A10})$$

Let $P = p + p_c c_x$ and $Y = I + p_c \omega$. Substituting equations (A8) into (A9), we have

$$y = \frac{p_c \omega + I - (p + p_c c_x)x}{q} = \frac{Y - Px}{q} \quad (\text{A11})$$

Substituting equation (A10) into equation (A7), we have

$$\frac{x}{y} = \left(\frac{1-\alpha}{\alpha} \frac{p + p_c c_x}{q} \right)^\frac{1}{\rho-1} = \left(\frac{1-\alpha}{\alpha} \frac{P}{q} \right)^\frac{1}{\rho-1} \quad (\text{A12})$$

Substituting equation (A11) into equation (A12), we have

$$x = \frac{\left(\frac{1-\alpha}{\alpha}\frac{P}{q}\right)^{\frac{1}{\rho-1}} \frac{Y}{q}}{1 + \left(\frac{1-\alpha}{\alpha}\frac{P}{q}\right)^{\frac{1}{\rho-1}} \frac{P}{q}} \quad (\text{A13})$$

Let $K = \left(\frac{1-\alpha}{\alpha}\frac{P}{q}\right)^{\frac{1}{\rho-1}} \frac{1}{q}$. Substituting equation (A13) into equation (A11), we have

$$y = \frac{1}{q(1+KP)} \quad (\text{A14})$$

$$x = \frac{KY}{1+KP} \quad (\text{A15})$$

The indirect utility function is

$$v(P, q, Y) = \left[\alpha \left(\frac{KY}{1+KP}\right)^\rho + (1-\alpha) \left(\frac{1}{q(1+KP)}\right)^\rho\right]^{\frac{1}{\rho}} \quad (\text{A16})$$

Appendix B

To calculate the substitution effect, we need to obtain the Hicksian demand function. The optimization model for the consumer can be represented as follows:

$$\begin{aligned} \min C(x, y) &= px + qy + p_c \psi \\ \text{s.t.} \quad &\begin{cases} \psi + \omega \geq c_x x & (\text{shadow price } \phi_1) \\ [\alpha x^\rho + (1-\alpha)y^\rho]^{\frac{1}{\rho}} \geq U & (\text{shadow price } \phi_2) \end{cases} \end{aligned} \quad (\text{B1})$$

where U is the minimum utility level required by the consumer.

The Karush-Kuhn-Tucker (KKT) optimality conditions for the inequality constrained optimization problems are

$$0 \leq x \perp p - \alpha \phi_1 [\alpha x^\rho + (1-\alpha)y^\rho]^{\frac{1}{\rho}-1} \cdot x^{\rho-1} + c_x \phi_2 \geq 0 \quad (\text{B2})$$

$$0 \leq y \perp q - ((1-\alpha)) \phi_1 [\alpha x^\rho + (1-\alpha)y^\rho]^{\frac{1}{\rho}-1} y^{\rho-1} \geq 0 \quad (\text{B3})$$

$$0 \leq \psi \perp p_c - \phi_2 \geq 0 \quad (\text{B4})$$

$$0 \leq \phi_1 \perp [\alpha x^\rho + (1-\alpha)y^\rho]^{\frac{1}{\rho}} - U \geq 0 \quad (\text{B5})$$

$$0 \leq \phi_2 \perp \psi + \omega - c_x x \geq 0 \quad (\text{B6})$$

Combining equations (B2), (B3) and (B4) produces:

$$\frac{\alpha \cdot x^{\rho-1}}{(1-\alpha)y^{\rho-1}} = \frac{p + c_x p_c}{q} \quad (\text{B7})$$

Let $P = p + p_c c_x$. Combining equations (B5) and (B6), we obtain the Hicksian demand function for consumer is

$$h_i(P, q, U) = [(1-\alpha) \left[\frac{\alpha q}{(1-\alpha)P} \right]^{\frac{\rho}{\rho-1}} + \alpha]^{\frac{-1}{\rho}} U \quad (\text{B8})$$

Computing the partial derivative of h_i with respect to P , we have

$$h_{ii} = \frac{1}{\rho-1} \alpha q U P^{-2} \frac{\left[\frac{\alpha q}{(1-\alpha)P} \right]^{\frac{1}{\rho-1}}}{\left[(1-\alpha) \left[\frac{\alpha q}{(1-\alpha)P} \right]^{\frac{\rho}{\rho-1}} + \alpha \right]^{\frac{1+\rho}{\rho}}} \quad (\text{B9})$$

References

- [1] Bin S, Dowlatabadi H. Consumer lifestyle approach to US energy use and the related CO2 emissions. *Energy Policy* 2005; 33(2): 197-208.
- [2] Nie H, Kemp R. Index decomposition analysis of residential energy consumption in China: 2002–2010. *Applied Energy* 2014; 121: 10-19.
- [3] Reinders A, Vringer K, Blok K. The direct and indirect energy requirement of households in the European Union. *Energy Policy* 2003; 31(2): 139-153.
- [4] Fan J, Wang S, Wu Y, et al. Buffer effect and price effect of a personal carbon trading scheme. *Energy* 2015; 82: 601-610.
- [5] Yuan B, Ren S, Chen X. The effects of urbanization, consumption ratio and consumption structure on residential indirect CO2 emissions in China: A regional

- comparative analysis. *Applied Energy* 2015; 140: 94-106.
- [6] Nie H, Kemp R. Index decomposition analysis of residential energy consumption in China: 2002–2010. *Applied Energy* 2014; 121: 10-19.
- [7] Bhattacharyya SC. Influence of India's transformation on residential energy demand. *Applied Energy* 2015; 143: 228-237.
- [8] Fleming D. Stopping the traffic. *Country Life* 1996; 140(19): 62-65.
- [9] DEFRA. Synthesis report on the findings from DEFRA's pre-feasibility study into personal carbon trading. 2008.
- [10] Li J, Fan J, Zhao D, et al. Allowance price and distributional effects under a personal carbon trading scheme. *Journal of Cleaner Production* 2015; 103(9): 50-59.
- [11] Blanford GJ, Richels RG, Rutherford TF. Feasible climate targets: The roles of economic growth, coalition development and expectations. *Energy Economics* 2009; 31: S82-S93.
- [12] Okagawa A, Masui T, Akashi O, Hijioka Y, Matsumoto K, Kainuma M. Assessment of GHG emission reduction pathways in a society without carbon capture and nuclear technologies. *Energy Economics* 2012; 34: S391-S398.
- [13] Seyfang G. Personal carbon trading: Lessons from complementary currencies. University of East Anglia, Norwich 2007.
- [14] Gabszewicz J, Sonnac N, Wauthy X. On price competition with complementary goods. *Economics Letters* 2011; 70: 431-437.
- [15] Starkey R. Personal carbon trading: A critical survey Part 2: Efficiency and effectiveness. *Ecological Economics* 2012; 73: 19-28.

- [16]McNamara D, Caulfield B. Examining the impact of carbon price changes under a personalised carbon trading scheme for transport. *Transport Policy* 2013; 30: 238-253.
- [17]Bristow AL, Wardman M, Zanni AM, Chintakayala PK. Public acceptability of personal carbon trading and carbon tax. *Ecological Economics* 2010; 69: 1824-1837.
- [18]Raux C, Marlot G. A system of tradable CO₂ permits applied to fuel consumption by motorists. *Transport policy* 2005; 12(3): 255-265.
- [19]Glover L. Personal Carbon Budgets for Transport. GAMUT, Australasian Centre for the Governance and Management of Urban Transport, University of Melbourne, 2011.
- [20]Fawcett T. Carbon rationing and personal energy use. *Energy & Environment* 2004; 15(6): 1067-1083.
- [21]Meyer A. Contraction & convergence: the global solution to climate change. Green Books, 2000.
- [22]Sorrell S. An upstream alternative to personal carbon trading. *Climate Policy* 2010; 10(4): 481-486.
- [23]Weitzman ML. Prices vs. quantities. *The Review of Economic Studies* 1974; 41: 477-491.
- [24]Pizer WA. Combining price and quantity controls to mitigate global climate change. *Journal of Public Economics* 2002; 85: 409-434.
- [25]Stranlund JK, Ben-Haim Y. Price-based vs. quantity-based environmental regulation under Knightian uncertainty: An info-gap robust satisficing perspective. *Journal of Environmental Management* 2008; 87: 443-449.
- [26]Harwatt H, Tight M, Bristow A L, et al. Personal Carbon Trading and fuel price

increases in the transport sector: an exploratory study of public response in the UK. 2011.

[27]Pearce D. The role of carbon taxes in adjusting to global warming. *The Economic Journal* 1991; 101: 938–948.

[28]Lockwood M. The economics of personal carbon trading. *Climate Policy* 2010; 10(4): 447-461.

[29]Starkey R. Personal carbon trading: A critical survey: Part 1: Equity. *Ecological Economics* 2012; 73: 7-18.

[30]Matthews L. Upstream, downstream: the importance of psychological framing for carbon emission reduction policies. *Climate Policy* 2010; 10(4): 477-480.

[31]Woerdman E. Organizing emissions trading: the barrier of domestic permit allocation. *Energy Policy* 2000; 28(9): 613-623.

[32]Ervola A, Lankoski J, Ollikainen M. Mitigation options and policies in agricultural sector: a theoretical model and application, 120th Seminar, September 2-4, 2010, Chania, Crete. European Association of Agricultural Economists, 2010 (109320).

[33]Alexeeva-Talebi V. Cost pass-through of the EU emissions allowances: Examining the European petroleum markets. *Energy Economics* 2011; 33: S75-S83.

[34]Jouvet P A, Solier B. An overview of CO 2 cost pass-through to electricity prices in Europe. *Energy Policy* 2013; 61: 1370-1376.

[35]Parag Y, Capstick S, Poortinga W. Policy attribute framing: A comparison between three policy instruments for personal emissions reduction. *Journal of Policy Analysis and Management* 2011; 30: 889-905.

- [36]Owen L, Edgar L, Prince S, et al. Personal carbon trading: public acceptability: a report to the Department for Environment, Food and Rural Affairs[J]. Opinion Leader & Enviro Consulting, London, 2008.
- [37]Bird J, Jones N, Lockwood M. Political acceptability of personal carbon trading: Findings from primary research. London, IPPR, 2008.
- [38]Jagers S C, Löfgren Å, Stripple J. Attitudes to personal carbon allowances: political trust, fairness and ideology. *Climate Policy* 2010; 10(4): 410-431.
- [39]Parag Y, Strickland D. Personal carbon budgeting: What people need to know, learn and have in order to manage and live within a carbon budget, and the policies that could support them. UK Energy Research Centre, Working paper 2009.
- [40]Parry IWH, Small KA. Does Britain or the United States have the right gasoline tax?. *The American Economic Review* 2005; 95(4): 1276-1289.
- [41]Van Praag B. Ordinal and cardinal utility: An integration of the two dimensions of the welfare concept. *Journal of Econometrics* 1991; 50: 69-89.
- [42]Mas-Colell A, Whinston MD, Green JR. *Microeconomics*. New York: Oxford University Press 1995.
- [43]Jakiela P. Equity vs. efficiency vs. self-interest: on the use of dictator games to measure distributional preferences. *Experimental Economics* 2013; 16(2): 208-221.
- [44]Prywes M. A nested CES approach to capital-energy substitution. *Energy Economics* 1986; 8(1): 22-28.
- [45]Hobbs BF, Bushnell J, Wolak FA. Upstream vs. downstream CO₂ trading: A comparison for the electricity context. *Energy Policy* 2010; 38: 3632-3643.

- [46] Varian HR. Microeconomics Analysis (3rd edition) Norton, New York 1992.
- [47] Koutsoyannis AP. Demand functions for tobacco. The Manchester School 1961; 31: 1-19.
- [48] Azevedo IML, Morgan MG, Lave L.. Residential and regional electricity consumption in the US and EU: How much will higher prices reduce CO2 emissions?. The Electricity Journal 2011; 24(1): 21-29.
- [49] US Census Bureau. American community survey. Available at: <http://www.census.gov/acs/www/2013>.
- [50] IEA. Electricity information 2003-2014. Available at: http://www.oecd-ilibrary.org/energy/electricity-information_20783442.
- [51] Seyfang G, Lorenzoni I, Nye M. Personal carbon trading: Notional concept or workable proposition? Exploring theoretical, ideological and practical underpinnings. CSERGE Working Paper EDM 2007.
- [52] Muratori M, Roberts MC, Sioshansi R, Marano V, Rizzoni G. A highly resolved modeling technique to simulate residential power demand. Applied Energy 2013; 107: 465-473.
- [53] Burtraw D, Fraas A, Richardson N. Greenhouse gas regulation under the clean air act: a guide for economists. Review of Environmental Economics and Policy 2011; 5(2): 293-313.
- [54] Varian HR. Goodness-of-fit in optimizing models. Journal of Econometrics 1990; 46(1): 125-140.
- [55] Brauneis A, Mestel R, Palan S. Inducing low-carbon investment in the electric power

- industry through a price floor for emissions trading. *Energy Policy* 2013; 53: 190-204.
- [56] Lecca P, McGregor P G, Swales J K, et al. The added value from a general equilibrium analysis of increased efficiency in household energy use. *Ecological Economics* 2014; 100: 51-62.
- [57] Raux C, Croissant Y, Pons D. Would personal carbon trading reduce travel emissions more effectively than a carbon tax?. *Transportation Research Part D: Transport and Environment* 2015; 35: 72-83.
- [58] Nelson T, Kelley S, Orton F. A literature review of economic studies on carbon pricing and Australian wholesale electricity markets. *Energy Policy* 2012; 49: 217-224.
- [59] Starkey R, Anderson K. Domestic tradable quotas: A policy instrument for the reduction of greenhouse gas emissions. Tyndall Centre for Climate Change Research, Norwich 2005.

Editor, UWA Economics Discussion Papers:
 Sam Hak Kan Tang
 University of Western Australia
 35 Sterling Hwy
 Crawley WA 6009
 Australia

Email: ecoadmin@biz.uwa.edu.au

The Economics Discussion Papers are available at:

1980 – 2002: <http://ecompapers.biz.uwa.edu.au/paper/PDF%20of%20Discussion%20Papers/>

Since 2001: <http://ideas.repec.org/s/uwa/wpaper1.html>

Since 2004: <http://www.business.uwa.edu.au/school/disciplines/economics>

ECONOMICS DISCUSSION PAPERS 2015		
DP NUMBER	AUTHORS	TITLE
15.01	Robertson, P.E. and Robitaille, M.C.	THE GRAVITY OF RESOURCES AND THE TYRANNY OF DISTANCE
15.02	Tyers, R.	FINANCIAL INTEGRATION AND CHINA'S GLOBAL IMPACT
15.03	Clements, K.W. and Si, J.	MORE ON THE PRICE-RESPONSIVENESS OF FOOD CONSUMPTION
15.04	Tang, S.H.K.	PARENTS, MIGRANT DOMESTIC WORKERS, AND CHILDREN'S SPEAKING OF A SECOND LANGUAGE: EVIDENCE FROM HONG KONG
15.05	Tyers, R.	CHINA AND GLOBAL MACROECONOMIC INTERDEPENDENCE
15.06	Fan, J., Wu, Y., Guo, X., Zhao, D. and Marinova, D.	REGIONAL DISPARITY OF EMBEDDED CARBON FOOTPRINT AND ITS SOURCES IN CHINA: A CONSUMPTION PERSPECTIVE
15.07	Fan, J., Wang, S., Wu, Y., Li, J. and Zhao, D.	BUFFER EFFECT AND PRICE EFFECT OF A PERSONAL CARBON TRADING SCHEME
15.08	Neill, K.	WESTERN AUSTRALIA'S DOMESTIC GAS RESERVATION POLICY THE ELEMENTAL ECONOMICS
15.09	Collins, J., Baer, B. and Weber, E.J.	THE EVOLUTIONARY FOUNDATIONS OF ECONOMICS
15.10	Siddique, A., Selvanathan, E. A. and Selvanathan, S.	THE IMPACT OF EXTERNAL DEBT ON ECONOMIC GROWTH: EMPIRICAL EVIDENCE FROM HIGHLY INDEBTED POOR COUNTRIES
15.11	Wu, Y.	LOCAL GOVERNMENT DEBT AND ECONOMIC GROWTH IN CHINA
15.12	Tyers, R. and Bain, I.	THE GLOBAL ECONOMIC IMPLICATIONS OF FREER SKILLED MIGRATION
15.13	Chen, A. and Groenewold, N.	AN INCREASE IN THE RETIREMENT AGE IN CHINA: THE REGIONAL ECONOMIC EFFECTS
15.14	Knight, K.	PIGOU, A LOYAL MARSHALLIAN?
15.15	Kristoffersen, I.	THE AGE-HAPPINESS PUZZLE: THE ROLE OF ECONOMIC CIRCUMSTANCES AND FINANCIAL SATISFACTION

15.16	Azwar, P. and Tyers, R.	INDONESIAN MACRO POLICY THROUGH TWO CRISES
15.17	Asano, A. and Tyers, R.	THIRD ARROW REFORMS AND JAPAN'S ECONOMIC PERFORMANCE
15.18	Arthmar, R. and McLure, M.	ON BRITAIN'S RETURN TO THE GOLD STANDARD: WAS THERE A 'PIGOU-MCKENNA SCHOOL'?
15.19	Fan, J., Li, Y., Wu, Y., Wang, S., and Zhao, D.	ALLOWANCE TRADING AND ENERGY CONSUMPTION UNDER A PERSONAL CARBON TRADING SCHEME: A DYNAMIC PROGRAMMING APPROACH
15.20	Shehabi, M.	AN EXTRAORDINARY RECOVERY: KUWAIT FOLLOWING THE GULF WAR
15.21	Siddique, A., Sen, R., and Srivastava, S.	AUSTRALIA-THAILAND TRADE: AN ANALYSIS OF COMPETITIVENESS AND THE EFFECTS OF THE BILATERAL FTA
15.22	Tyers, R.	SLOWER GROWTH AND VULNERABILITY TO RECESSION: UPDATING CHINA'S GLOBAL IMPACT
15.23	Arthmar, R. and McLure, M.	PIGOU ON WAR FINANCE AND STATE ACTION
15.24	Wu, Y.	CHINA'S CAPITAL STOCK SERIES BY REGION AND SECTOR
15.25	Clements, K. and Si, J.	ENGEL'S LAW, DIET DIVERSITY AND THE QUALITY OF FOOD CONSUMPTION
15.26	Chen, S.	SHIFTS OF DISTORTION AND CORRUPTION OVER LOCAL POLITICAL CYCLES IN CHINA
15.27	Chen, S.	THE EFFECT OF A FISCAL SQUEEZE ON TAX ENFORCEMENT: EVIDENCE FROM A NATURAL EXPERIMENT IN CHINA
15.28	Jetter, M.	BLOWING THINGS UP: THE EFFECT OF MEDIA ATTENTION ON TERRORISM
15.29	Tang, S.	MEDIUM-TERM MACROECONOMIC VOLATILITY AND ECONOMIC DEVELOPMENT: A NEW TECHNIQUE
15.30	Alim, A., Hartley, P. and Lan, Y.	ASIAN SPOT PRICES FOR LNG OTHER ENERGY COMMODITIES
15.31	Gannon, B., Harris, D., Harris, M., Magnusson, L., Hollingsworth, B., Inder, B., Maitra, P. and Munford, L.	NEW APPROACHES TO ESTIMATING THE CHILD HEALTH-PARENTAL INCOME RELATIONSHIP
15.32	Czaika, M. and Parsons, C.	THE GRAVITY OF HIGH SKILLED MIGRATION POLICIES
15.33	Parsons, C., Rojon, S., Samanani, F. and Wettach, L.	CONCEPTUALISING INTERNATIONAL HIGH-SKILLED MIGRATION
15.34	Chen, S.	VAT RATE DISPERSION AND TFP LOSS IN CHINA'S MANUFACTURING SECTOR
15.35	Tait, L., Siddique, A. and Chatterjee, I.	FOREIGN AID AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICA

**ECONOMICS DISCUSSION PAPERS
2016**

DP NUMBER	AUTHORS	TITLE
16.01	Xu, R., Wu, Y. and Luan, J.	ANALYSIS OF FARMERS' WILLINGNESS TO ADOPT GENETICALLY MODIFIED INSECT-RESISTANT RICE IN CHINA
16.02	Lia, Y., Fan, J., Zhao, D., Wu, Y. and Li, J.	TIERED GASOLINE PRICING: A PERSONAL CARBON TRADING PERSPECTIVE
16.03	Clements, K.W., Lan, Y. and Si, J.	UNCERTAINTY IN CURRENCY MISPRICING
16.04	Parsons, C. and Vézina, P.L.	MIGRANT NETWORKS AND TRADE: THE VIETNAMESE BOAT PEOPLE AS A NATURAL EXPERIMENT
16.05	Chang, S., Connelly, R. and Ma, P.	WHAT WILL YOU DO IF I SAY 'I DO'? : THE EFFECT OF THE SEX RATIO ON TIME USE WITHIN TAIWANESE MARRIED COUPLES
16.06	Yu, F. and Wu, Y.	BIASES IN PATENT EXAMINATION AND FIRMS' RESPONSES: EVIDENCE FROM THE PHARMACEUTICAL INDUSTRY
16.07	Fan, J., Li, J., Wu, Y., Wang, S. and Zhao, D.	THE EFFECTS OF ALLOWANCE PRICE ON ENERGY DEMAND UNDER A PERSONAL CARBON TRADING SCHEME
16.08	Golley, J., Tyers, R. and Zhou, Y.	CONTRACTIONS IN CHINESE FERTILITY AND SAVINGS: LONG RUN DOMESTIC AND GLOBAL IMPLICATIONS
16.09	McGrath, G. and Neill, K.	FOREIGN AND DOMESTIC OWNERSHIP IN WESTERN AUSTRALIA'S GAS MARKET
16.10	Clements, K.W. and Si, J.	SIMPLIFYING THE BIG MAC INDEX
16.11	Priyati, R.Y. and Tyers, R.	PRICE RELATIONSHIPS IN VEGETABLE OIL AND ENERGY MARKETS
16.12	Wu, J., Wu, Y. and Wang, B.	THE GREENNESS OF CHINESE CITIES: CARBON DIOXIDE EMISSION AND ITS DETERMINANTS
16.13	Arslan, C., Dumont, J.C., Kone, Z., Özden, Ç., Parsons, C. and Xenogiani, T.	INTERNATIONAL MIGRATION TO THE OECD IN THE TWENTY-FIRST CENTURY
16.14	Tomioka, K. and Tyers, R.	HAS FOREIGN GROWTH CONTRIBUTED TO STAGNATION AND INEQUALITY IN JAPAN?
16.15	Donovan, J. and Hartley, P.	RIDING THE IRON ORE CYCLE: ACTIONS OF AUSTRALIA'S MAJOR PRODUCERS