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Technical Characteristics in the Diffusion of Cleaner Residential Heating System in China: The Case of Air-Source Heat Pump Technology

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Abstract

This study aims to explore the technical characteristics that affect user satisfaction with air-source heat pump technology which is recognized as one typical cleaner residential heating system and being promoted in China in response to the national "coal to electricity" policy. Moderated hierarchical linear regression analysis was conducted to analyze data from a questionnaire survey of 256 residents in suburban Beijing. Empirical results indicated that product convenience, product design, product reliability, product knowledge, and total cost, respectively, affect user satisfaction, but product safety has no significant effect on user satisfaction. Meanwhile, total cost is an important contingent factor that might weaken the positive effects of product convenience (or product design) on user satisfaction. Our research provides empirical evidence for identifying factors that influence user satisfaction with cleaner residential heating system in response to new energy policy and further provides useful managerial implications for market practice.

Keywords

cleaner residential heating system, air-source heat pump technology, technical characteristics, user satisfaction, "coal to electricity" policy

Introduction

Background

Since the start of economic reform and openness up in 1978, China has experienced rapid economic growth and significant urbanization. However, China's traditional model of economic growth requires huge resource investment (e.g., labor, capital, land, and energy). The Chinese energy resource endowment, with the characteristics of "rich in coal, short in oil and gas," results in the typical imbalance of energy consumption structure in which coal is the principal energy source of industrial sectors and human life (Liu, Chen, Wang, Campana, & Yan, 2016; Marigo, Foxon, & Pearson, 2010). Meanwhile, it has led to many researchers predicting that coal will remain the biggest energy source for China in the foreseeable future (Meng & Xiong, 2018). However, low efficiency of coal consumption has induced huge pollution emissions and severe environmental destruction, which is widely acknowledged as one important contributor to the growing rate of various diseases such as lung cancer, respiratory illness, and cardiovascular disease (Qu, Xu, Qu, Yan, & Wang, 2017; Weldu, Assefa, & Jolliet, 2017).

In the case of residential heating system (RHS), coal historically dominates energy consumption in Northern China (Zhao & Luo, 2018). By the end of 2017, 83% of Northern China still uses coal as the residential heating energy source, and the remaining 17% of Northern

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China relies on other energies such as gas, nuclear power, geothermal energy, and other renewable energies (Qu, 2018). It indicates that there is high potential for residential heating sector to introduce cleaner heating technologies and optimize its energy structure so as to reduce pollution emissions. Particularly in recent years, Northern China has suffered from severe fog, mist, and haze during the winter season, and $PM_{2.5}$ (Particulate matter) value repeatedly made new records. Due to the poor performance of environmental governance, both the Chinese central and regional governments have been engaged in domestic and international debates (Zuo, Hua, Dong, & Hao, 2017). Previous studies have strongly argued that RHS based on small size coal-fired boilers, which are often used in suburban and rural regions, are one of the important generators of pollutant emissions. According to the 2016 Annual Report on China Building Energy Efficiency released by Building Energy Research Center of Tsinghua University (2016), the $PM_{2.5}$ emission of small size coal-fired boilers in Beijing was 3.7 g/kg, 4 to 10 times higher than other heating technologies. This indicates that the energy efficiency of RHS based on small size coal-fired boilers is relatively low, and how to overcome such dilemma is an interesting topic within academic research and market practice.

To reduce pollution emissions and build a healthy residential environment, the Chinese government has proposed various environmental policies regarding the residential heating sector (Su, Zhou, Gu, & Wu, 2019; Wang, He, Qiu, Liu, Li, & Dong, 2018). For instance, in 2013, the State Council proposed the Action Plan on Air Pollution Control, including the coal to electricity project (Zhang, Wang, Hao, Wang, Wang, Chai, & Li, 2016). This plan states that by the end of 2017, all cities should decrease the concentration of inhalable particles by 10% compared with 2012 levels. To this end, in March 2017, the Ministry of Environmental Protection confirmed that Northern China's "2 + 26" cities,[1] which is greatly reliant on coal energy and faced severe environmental pollution, should shift their energy consumption source of RHS from coal to cleaner energies. In particular, four cities (Beijing, Tianjin, Langfang, and Baoding) are required to dismantle small size coal-fired boilers by the end of October 2017. By the end of November 2017, the Ministry of Environmental Protection reported that over 4 million households in major cities in Northern China have installed new types of RHS, such as air-source heat pump technology (ASHP), gas-fired boilers, and other cleaner heating technologies.

As an important part of China's energy policy, the primary aim of coal to electricity is to shift energy consumption sources of RHS from coal to electric power, thus reducing dust, CO_2, SO_2, and other pollutant emissions (Zhao & Luo, 2018). Considering that coal to electricity is gradually becoming a significant policy in the field of the residential heating sector, some researchers attempted to investigate the newly established RHS according to this policy. For instance, Liu (2017) analyzed the cost of new RHS using electric power and suggested that government should encourage energy-saving reconstruction of residences, change the current subsidy model, and improve subsidy efficiency. Based on a case study of Liaoning Province, Zhu, Zhang, Liang, Zhang, and Li (2017) investigated the effects of supply technologies of new electric power sources (e.g., water, wind, solar, and nuclear) on energy consumption and thermal properties and further discussed the topic of how these sources of new energy can underpin the implementation of coal to electricity. These empirical studies mainly focused on cost affordability or the technology supply in accordance with the coal to electricity policy. Unfortunately, there have been no studies investigating the policy effects at the individual level, particularly user satisfaction with cleaner RHS. In other words, the first aim of study is to examine whether users are satisfied with RHS reforms (coal to electricity) and whether environmental policies have generated expected outcomes from the perspective of energy customers. According to diffusion of innovation theory, users may have important effects on the decision-making process of environmental policies, which might provide authoritative guidelines for social behavior and activities (Holahan & Arnold, 2013). Stakeholder theory also suggests that firms should focus on the interests of its customers (Yu & Choi, 2014). That is, customers' preferences and attitudes not only directly impact the sales and profitability of innovative products, but their involvement in innovation activities also help develop market-orientated products (Nielsen, Reisch, & Thogersen, 2016; Su, Du, Sohn, & Xu, 2017). Considering that technical characteristics might reflect the overall quality of RHS (Sopha & Klöckner, 2011), this study also attempts to examine what roles these technical characteristics might play in user satisfaction in the context of China in which environmental policy to reduce pollutants emissions and improve environmental quality is receiving considerable attention.

Literature Review About User Satisfaction

User satisfaction can be defined as the perceived degree in which users are pleased with the products or services provided by a company. User satisfaction reflects the functions of goods that fulfill user expectations in terms of overall quality in relation to his or her payment. In other words, user satisfaction may enhance our understanding of to what degree innovative products or services provided by suppliers meet user needs or surpass their expectations (Michelsen & Madlener, 2017; Su & Sohn, 2015).

Previous studies examining the roles of user satisfaction predominantly focus on the individual-level or the firm-level perspective. At the individual level, user satisfaction might reflect whether products or services provided by firms meet user needs in relation to their payment. User satisfaction is a leading indicator of repurchase intentions, loyalty, and positive commendation (Rogers, 2003). Excellent user satisfaction can increase repurchase possibility, maintain high loyalty, and generate good word-of-mouth, and thus affects the diffusion of products. At the firm level, a high-level user satisfaction might help build a better understanding of the changes in requirements of consumers and develop customized products (Tjader, May, Shang, Vargas, & Gao, 2014). In short, user satisfaction can provide business managers with a metric of how to manage and improve their businesses in rapidly changing business environments. Therefore, user satisfaction with innovative products or services would largely affect the diffusion of innovation and further determines a company's market potential and sale income. In the case of cleaner RHS, an increasing number of innovative technologies have been developed and diffused in response to the environmental pollution and climate change. To help business managers develop market-oriented products for residential heating sector, it is necessary to examine whether early-users are satisfied with these innovative technologies.

Literature Review About Technical Characteristics of RHS and User Satisfaction

Diffusion of innovation is a theory that seeks to explain how, why, and at what rate innovative technologies spread, indicating that the spread of an original technology is mainly influenced by five key elements: invention, users, communication channels, time, and social system. Moreover, this theory classifies adopters into five groups: innovators, early-adopters, early-majority, late-majority, and laggards (Rogers, 2003). According to this theory, the rate of the creation and diffusion of innovative products is closely related to the users' perception (especially early adopters) of technical characteristics (Su, Du, Sohn, & Xu, 2017). That is, because technical characteristics might reflect the overall quality, which would largely determine whether innovative product can meet users' needs (Abdolmaleki & Ahmadian, 2016).

Along with the emergence of environmental protection and sustainable growth, innovation related to environmental issues has received a great attention by R&D activities and market practice. In the case of RHS, innovation has created various cleaner residential heating technologies such as ASHP, wood pellet heating, and solar photovoltaics, which are widely acknowledged as important driving forces of improving human life and environmental quality (Marigo et al., 2010; Sopha & Klöckner, 2011). Hence, some scholars have attempted to investigate the diffusion of innovative RHS by exploring the effects of technical characteristics on user satisfaction. For instance, using a study of Norwegian household's adoption of wood pellet heating, Sopha and Klöckner (2011) suggested that users often payed more attention to product quality (e.g., functional reliability) than social norms and values. Focusing on early adopters of the wood-pellet heating system in Norway, Skjeverak and Sopha (2012) found that technical factors (maintenance time, pellet stove, and suppliers or vendors) were directly related to user satisfaction. Based on a survey of modern pellet boilers in Austria and Germany, Büchner, Schraube, Carlon, Sonntag, Schwarz, Verma, & Ortwein (2015) suggested that better system design, less frequent ignitions, and higher operational loads play crucial roles in user satisfaction with their pellet boiler. Using original data from 2,135 homeowners who had recently adopted an RHS in Germany, Michelsen and Madlener (2017) found that adoption motivation, knowledge-related RHS, and attitude toward new RHT have strong impacts on user satisfaction, and there are few differences in user satisfaction in terms of different sociodemographic samples (gender, age, university degree, and monthly income). Franceschinis, Thiene, Scarpa, Rose, Moretto, & Cavalli (2017) employed a choice experiment and a Latent Class-Random Parameter model to study the preferences of users regarding RHS based on renewable resources using the indicators of complexity, compatibility, trialability, relative advantage, performance risk, social risk, knowledge, and environmental friendliness. According to these empirical studies, we conclude five technical characteristics (product convenience, product design, product safety, product reliability, and product knowledge) that may largely impact residents' satisfaction with new RHS. Meanwhile, we propose the following hypotheses:

Hypothesis 1a: Product convenience has a positive effect on user satisfaction with ASHP;

Hypothesis 1b: Product design has a positive effect on user satisfaction with ASHP;

Hypothesis 1c: Product safety has a positive effect on user satisfaction with ASHP;

Hypothesis 1d: Product reliability has a positive effect on user satisfaction with ASHP;

Hypothesis 1e: Product knowledge has a positive effect on user satisfaction with ASHP.

Based on the review of the relevant literature, we find that: (a) these studies mainly focused on the context of Western countries, but there exists limited literature investigating the case of China, in which the government has enhanced environmental protection and strengthened pollutants emission controls; (b) the research objectives of these studies mainly focused on the pellet heating system, which is broadly used in Western countries, and few studies examined other cleaner RHS such as ASHP which is currently being promoted in developing countries such as China; and (c) these empirical studies explored the liner relationships between technical characteristics and user satisfaction, but ignored the importance of contingency variable. Consumer behavior theory suggests payment might affect the perceived importance of technical characteristics in user satisfaction with products (Espeland & Stenvik, 1991; Lopez-Mosquera & Sanchez, 2016; Sen, Sahaa, & Hernandeza, 2007). In this regard, this study not only examines the effects of technical characteristics of ASHP on user satisfaction but also explores the contingent role of total cost of ASHP on user satisfaction in the context of China. Meanwhile, we propose the following hypotheses:

Hypothesis 2a: Total cost moderates the relationship between product convenience and user satisfaction with ASHP;

Hypothesis 2b: Total cost moderates the relationship between product design and user satisfaction with ASHP;

Hypothesis 2c: Total cost moderates the relationship between product safety and user satisfaction with ASHP;

Hypothesis 2d: Total cost moderates the relationship between product reliability and user satisfaction with ASHP;

Hypothesis 2e: Total cost moderates the relationship between product knowledge and user satisfaction with ASHP.

Methods

Questionnaire Design

Regarding data collection, we attempted to develop a questionnaire that followed the Tailored Design Method (Dillman, Smyth, & Christian, 2008). In the first step, we searched for indicators from previous literature regarding the technical characteristics of innovative products and user satisfaction, especially those of the residential heating sector. For instance, five variables (product convenience, product design, product safety, product reliability, and product knowledge) for describing technical characteristics of RHS were developed according to the literature review. In the second step, we invited two RHS marketing managers and two scholars in the field of cleaner technologies to evaluate our draft questionnaire. Finally, we made some revisions in accordance with their recommendations. The final questionnaire for field survey consisted of three parts. Part 1 concerned the sociodemographic information of respondents: gender, age, education degree, and family monthly income. Part 2 lists the explanatory variables (product convenience, product design, product safety, product reliability, product knowledge, and total cost) and their measurement items. The outcome variable (user satisfaction) and its measurement items were presented in Part 3. Both the six explanatory variables and outcome variable (user satisfaction) were measured using a 5-point Likert-type scale.

Independent Variables

1. Product convenience: It refers to all aspects of a product that simplifies human life and brings comfort to consumers (Ku & Fan, 2009). Convenience was measured by three items on a 5-point Likert-type scale: (a) if needed, RHS can be easily used; (b) RHS brings much comfort to my life; and (c) using RHS results in clean indoor air. The reliability of product convenience ($\alpha = .82$) was higher than the recommended .7 benchmark.
2. Product design: It can be defined as the effective and efficient presentation or development of product components (Kuo, Chen, Liu, Tu, & Yeh, 2014). Product design was measured by four items on a 5-point Likert-type scale: (a) the design of RHS is suitable for household, (b) the design of RHS is humanized, (c) the design of RHS is attractive and beautiful, and (d) my family enjoys the design of RHS. An acceptable reliability value was obtained for product design (α=.85).
3. Product safety: It means safety-related concerns or questions which may affect human health (Knight & Rovida, 2014). Risk and safety throughout the product life-cycle is closely related to customers' experience and assessment, and primarily determines customer satisfaction. We measured safety using two items on a 5-point Likert-type scale: (a) RHS is safe during heating times and (b) RHS does not harm the health of our family. The reliability of product safety ($\alpha = .79$) exceeded .7 benchmark.
4. Product reliability: Product reliability is an important indicator to measure the degree of which RHS is reliable (Sopha & Klöckner, 2011). We measured

reliability using three items on a 5-point Likert-type scale: (a) the total quality of RHS is reliable, (b) the heating performance of RHS is reliable, and (c) the after service (A/S) of RHS is reliable. The reliability of product reliability was .82, exceeding the .7 benchmark.

5. Product knowledge: Keeping particular knowledge or skills related to new products can help consumers have a better understanding of many aspects of innovative products or services and further impacts user satisfaction (Sangtani & Murshed, 2017). Following the previous literature (Michelsen & Madlener, 2017; Skjeverak & Sopha, 2012), the term product knowledge was measured using three items on a 5-point Likert-type scale: (a) how familiar were you with the strengths (or weaknesses) of RHS installed in your house, (b) how familiar were you with the characteristics of RHS installed in your house, and (c) how familiar were you with the user guidance of RHS installed in your house. The reliability of product knowledge ($\alpha = .95$) was well above the recommended .7 benchmark.

Dependent Variables

User satisfaction: User satisfaction is the measure of how users' needs or responses are delivered to their expectation (Salazar, Lelah, & Brissaud, 2015). It is a crucial indicator in measuring the success of innovative products and further impacts customer loyalty and market potential. In this study, we measured the consumer behavioral variable "user satisfaction" with newly installed RHS by three items on a 5-point Likert-type scale: (a) to what extent are you satisfied with RHS, (b) to what extent are you willing to consistently use RHS, and (c) to what extent are you willing to positively recommend RHS to others. The reliability of user satisfaction ($\alpha = .85$) was higher than the usual .7 benchmark.

Moderating Variable

In this study, total cost was a moderator in the relationship between the independent variables and dependent variable. Consumer behavior theory suggests that economic factors (e.g., cost) are a critical determinant that influences consumer satisfaction with products or services (Dagoumas & Polemis, 2017; Sullivan, Suddeth, Vardell, & Vojdani, 1999). However, we argue that total cost might also influence the effects of users' perception of technical characteristics on their satisfaction with innovative products. That is because high-quality technical characteristics often means high payment and thus affects users' experiences of innovative products. Our study defined the total cost as the costs of installation, operation, and A/S of RHS. In accordance with the measurement method developed by Michelsen and Madlener (2017), the total cost of newly installed RHS was measured by one item on a 5-point Likert-type scale (from *very cheap* to *very expensive*): How do you evaluate the total cost of your RHS.

Control Variables

In accordance with the suggestion of Michelsen and Madlener (2017), control variables of this study mainly focused on the sociodemographic information of respondents: gender (male or female), age (five levels: younger than 20, 20–29, 30–39, 40–49, or older than 50 years), education degree (five levels: senior school or under, high school, college, undergraduate, or graduate), and family monthly income (six levels: less than 5,000, 5,000–10,000, 10,000–15,000, 15,000–20,000, 20,000–25,000, or more than 25,000).

Data Collection

Due to the coal to electricity policy, an increasing number of residents in suburban and rural areas of Northern China have installed ASHP that is a system that absorbs heat from outside and releases it inside a building or vice versa. This technology is similar to a refrigerator or freezer or air conditioning unit, which can provide fairly low-cost space heating (or cooling) and high efficiency. Compared with coal-fired boilers and gas-fired boilers, ASHP is much cleaner and generates lower carbon emission. Beijing is one city that was required to implement the coal to electricity policy, and we choose its suburban residents who have installed ASHP as our research sample. The primary reasons why suburban Beijing was chosen as the research region included (a) Beijing is concentrating on shifting its residential heating energy from coal to cleaner residential heating energy such as electricity; (b) as the political and cultural center in China, Beijing scarcely confronts with a shortage of energy supply which may result in negative commendations to the current coal to electricity policy (Liu, Chen, Wang, Campana, & Yan, 2016); and (c) unlike urban areas where mainly adopt district heating systems, suburban residents often have to decide their RHT by themselves. To collect data, the Resource and Environmental Protection Department of the National Audit Office which is authorized to supervise the implementation processes of the coal to electricity policy was invited to assist in contacting our research respondents. We obtained directories of ASHP adopters of suburban Beijing from this office and then we conducted a field survey to distribute questionnaire. After 1 month, we obtained data from 273 suburban residents who had installed ASHP, among which 17 were excluded for missing data. Therefore, these 256 respondents were selected as our research sample.

Technical Method

The technical analysis tools employed in this study were SPSS 23.0 and AMOS 22.0. We conducted the moderated hierarchical linear regression analysis (MHLRA). That is because not only can MHLRA examine the direct effects of an explanatory variable on an explained variable but can also identify whether a variable moderates the relationship between an explanatory variable and an explained variable (Stam & Elfring, 2008). In Step 1, four control variables (gender, age, education level, and family monthly income) were included, and subsequently in Step 2, we added the explanatory variables (product convenience, product design, product safety, product reliability, product knowledge, and total cost). In Step 3, we entered five product terms Product Convenience × Total Cost, Product Design × Total Cost, Product Safety × Total Cost, Product Reliability × Total Cost, and Product Knowledge × Total Cost for examining the moderating effects of total cost on the relationships between the technical characteristics and user satisfaction.

Results

This section presents the sample information, reliability, validity, common method bias analysis, correlation analysis, and the results of the MHLRA.

Descriptive Statistics of Sample

In the case of gender, the number of male respondents was 112 (43.75%) and the number of female respondents was 144 (56.25%). The age profile showed that participants aged 30 to 39 years had the highest number of respondents (40.23%), followed by respondents aged 40 to 49 years (37.11%), respondents aged 50 years and older (13.28%), and respondents aged 20 to 29 years (9.38%). Most respondents had good educational background: undergraduate (34.38%), college (30.86%), high school (20.70%), graduate (9.37%), and senior school (4.69%). In addition, 93 respondents' (36.33%) monthly family income ranged 5,000 to 10,000 Yuan RMB, 64 respondents' (25%) monthly family income ranged 10,000 to 15,000 Yuan RMB, 31 respondents' (12.11%) monthly family income was between 15,000 and 20,000 Yuan RMB, 29 respondents' (11.33%) monthly family income ranged 20,000 to 25,000 Yuan RMB, 21 respondents' (8.20%) monthly family income was less than 5,000 Yuan RMB, and 18 respondents' (7.03%) monthly family income exceeded 25,000 Yuan RMB.

Reliability and Validity

We calculated Cronbach's alpha (α) and composite reliability to assess the reliability of variables. As shown in Table 1, the Cronbach's α values were higher than .80, and the composite reliability values also exceeded .80, both of which indicate acceptable reliability.

The maximum likelihood estimation was used to conduct confirmatory factor analysis for evaluating the validity of each construct. As shown in Table 1, the factor loadings of all constructs exceeded 0.60, and

Table 1. Confirmatory Factor Analysis, Standard Estimates, and Coefficient Alpha ($N = 256$).

Variables and items	Loading	Alpha
Product convenience (CR = 0.89; AVE = 0.73)		.82
(1) if needed, RHS can be easily used;	0.87	
(2) RHS brings much comfort to my life;	0.86	
(3) using RHS results in clean indoor air.	0.83	
Product design (CR = 0.86; AVE = 0.61)		
(1) the design of RHS is suitable for households;	0.84	
(2) the design of RHS is humanized;	0.81	
(3) the design of RHS is reasonable;	0.80	
(4) I enjoy the design of RHS.	0.67	
Product safety (CR = 0.83; AVE = 0.71)		
(1) RHS is safe during heating times;	0.82	
(2) RHS does not harm my health.	0.87	
Product reliability (CR = 0.88; AVE = 0.71)		
(1) the total quality of RHS is reliable;	0.86	
(2) the heating performance of RHS is reliable;	0.92	
(3) the A/S of RHS is reliable.	0.73	
Product knowledge (CR = 0.94; AVE = 0.85)		
(1) how familiar were you with the strengths (or weaknesses) of RHS installed in your house;	0.89	
(2) how familiar were you with the characteristics of RHS installed in your house;	0.94	
(3) how familiar were you with the user guidance of RHS installed in your house.	0.93	
User satisfaction (CR = 0.91; AVE = 0.77)		.85
(1) to what extent are you satisfied with newly installed RHS;	0.87	
(2) to what extent are you willing to consistently use this RHS;	0.89	
(3) to what extent are you willing to positively recommend this new RHS to others.	0.87	

Note. CR = composite reliability; AVE = average variances extracted; RHS = residential heating system; A/S = after service.

the Kaiser–Meyer–Olkin (KMO) values of independent variables and dependent variables were 0.74 and 0.73, respectively, and therefore, the construct validity of the measures exceeded the lowest acceptable level (0.60). In addition, the average variances extracted (AVE) was used to measure the convergent validity. Table 1 shows that all AVE values exceeded 0.6, indicating sufficient convergent validity for all measures. In addition, we also compared the square roots of the AVE and Pearson correlations to assess the discriminant validity. As shown in Table 2, all Pearson correlations were smaller than the square roots of the AVE (marked in bold type), which also indicate that all measures have a good discriminant validity.

Common Method Bias

Previous literature suggested that common method bias might be present when the same respondents answer all items of the questionnaire according to perceptual judgment (Zhang, Wang, Hao, Wang, Wang, Chai, & Li, 2016). To minimize the common method bias, we employed two approaches in this study. First, respondents were explained that this scientific survey was anonymous and therefore lacked any potential fear of personal privacy issues. Meanwhile, statements of all items were listed as clear, simple, and as easy to understand as possible (Xie, Jia, Meng, & Li, 2017). Second, we employed the Harman's single-factor test, which was widely used in previous studies to examine the presence of common method bias (Park & Ghauri, 2011). Our analysis results showed that the first factor loading was 29.95%, lower than 40%, which also indicates that the presence of common method bias was not an issue.

Correlation Analysis

To test the correlation of variables, we employed the Pearson correlation test which examines whether there is the possibility of multicollinearity. As shown in Table 2, the Pearson correlations for all variables were lower than .7. According to the previous literature, multicollinearity did not exist in this study (Tabachnick & Fidell, 1996). In addition, the mean of user satisfaction is 3.31, suggesting that residents of suburban Beijing perceive that the satisfaction with ASHP is a little bit higher than mediate level ("neither satisfied nor dissatisfied"). Furthermore, it means much potential to improve user satisfaction of ASHP.

Empirical Results

Table 3 presents the MHLRA results and shows the changes in the variance explained (ΔR^2), which is generally used to indicate the significance of the interaction effect. Model 1 presented the regression results of four control variables to user satisfaction. It suggested that gender, education level, and family monthly income had no significant effects on user satisfaction with ASHP. However, age ($\beta = -0.62$, $T = 1.85$, $p = .06 < .1$) might affect user satisfaction with ASHP, demonstrating that older respondents featured lower user satisfaction with ASHP. However, the control variables accounted for only 2% of the total variance in the outcome variable. Model 2 showed that total cost ($\beta = -0.65$, $T = 1.93$, $p = .05 < .1$), product convenience ($\beta = 0.61$, $T = 13.82$, $p = .00 < .01$), product design ($\beta = 0.17$, $T = 2.14$, $p = .03 < .05$), product reliability ($\beta = 0.30$, $T = 7.39$, $p = .00 < .01$), and product knowledge ($\beta = 0.39$, $T = 9.24$, $p = .00 < .01$) might significantly affect user satisfaction, but product safety ($\beta = 0.06$, $T = 1.54$, $p = .12$) had no significant effects on user satisfaction. Model 2 explained 59% of the total variance and therefore it might be a good approach to predict the important technical characteristics in the diffusion of ASHP. Model 3 demonstrated the moderating role of total cost in the relationships between technical characteristics and

Table 2. Means, *SDs*, and Correlations for Variables ($N = 256$).

Variables	Mean	*SD*	1	2	3	4	5	6	7	8	9	10	11
1. Gender	1.56	0.49											
2. Age	38.94	8.32	0.01										
3. Education level	4.10	0.82	0.08	−0.14*									
4. Monthly family income	12194.92	7626.99	0.02	0.51**	−0.05								
5. Total cost	4.42	0.77	0.10	0.07	0.00	0.17**							
6. Product convenience	2.94	0.68	0.09	0.05	−0.06	0.14*	0.08	**0.85**					
7. Product design	3.39	0.70	0.10	−0.13*	0.08	−0.02	0.25**	0.16**	**0.78**				
8. Product safety	3.65	0.67	0.05	0.02	0.09	0.08	0.23**	0.05	0.55**	**0.84**			
9. Product reliability	3.44	0.69	0.09	−0.08	0.07	0.05	0.20**	0.16**	0.63**	0.65**	**0.84**		
10. Product knowledge	3.35	0.73	0.03	−0.03	0.01	−0.02	0.16**	0.05	0.33**	0.28**	0.43**	**0.92**	
11. User satisfaction	3.31	0.76	0.09	−0.09	0.02	0.05	0.14*	0.11	0.61**	0.55**	0.66**	0.42**	**0.88**

Note. Numbers in bold type indicate the square root of the AVE. AVE = average variance extracted.
*$p < .05$. **$p < .01$.

Table 3. Moderated Regression Analysis Results.

	Model 1		Model 2		Model 3	
Variables	β (*SE*)	T (sig.)	β (*SE*)	T (sig.)	β (*SE*)	T (sig.)
Gender	0.17 (0.13)	1.36 (0.18)	0.04 (0.08)	0.52 (0.60)	0.09 (0.08)	1.17 (0.24)
Log (Age)	−0.62 (0.33)	1.85*	−0.22 (0.22)	1.01 (0.32)	−0.21 (0.22)	0.96 (0.34)
Education level	0.00 (0.08)	0.05 (0.96)	−0.06 (0.05)	1.18 (0.24)	−0.07 (0.05)	1.49 (0.14)
Log (monthly family income)	0.16 (0.13)	1.19 (0.24)	0.10 (0.09)	1.09 (0.28)	0.11 (0.09)	1.24 (0.22)
Product convenience			0.61 (0.04)	13.82***	−0.19 (0.35)	0.54 (0.59)
Product design			0.17 (0.08)	2.14**	0.48 (0.19)	2.55**
Product safety			0.06 (0.04)	1.54 (0.12)	0.29 (0.31)	0.94 (0.35)
Product reliability			0.30 (0.04)	7.39***	0.41 (0.29)	1.38 (0.17)
Product knowledge			0.39 (0.04)	9.24***	0.66 (0.34)	1.95*
Total cost			−0.65 (0.33)	1.93*	−0.57 (0.52)	1.09 (0.28)
Product Convenience × Total Cost					0.52 (0.23)	2.29**
Product Design × Total Cost					−0.27 (0.10)	2.68**
Product Safety × Total Cost					−0.15 (0.20)	0.76 (0.45)
Product Reliability × Total Cost					−0.08 (0.19)	0.39 (0.69)
Product Knowledge × Total Cost					−0.19 (0.23)	0.87 (0.38)
F	1.37 (sig. 0.25)		34.97 (sig. 0.00)		26.18 (sig. 0.00)	
R^2	0.02		0.59		0.62	
Adjusted R^2	0.01		0.57		0.60	
F for model changes	1.37		56.17		4.13	
ΔR^2	0.02		0.57		0.03	

Note. "Log" means the values of the ln (odds) which were calculated by SPSS.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4. Results for Hypotheses.

No.	Hypotheses	Support or not	*T*	*p*
Hypothesis1a	Product Convenience → User Satisfaction	Supported	13.82	<.001
Hypothesis1b	Product Design → User Satisfaction	Supported	2.14	<.01
Hypothesis1c	Product Safety → User Satisfaction	Not supported	1.54	.12
Hypothesis1d	Product Reliability → User Satisfaction	Supported	7.39	<.001
Hypothesis1e	Product Knowledge → User Satisfaction	Supported	9.24	<.001
Hypothesis2a	Product Convenience × Total Cost → User Satisfaction	Supported	2.29	<.01
Hypothesis2b	Product Design × Total Cost → User Satisfaction	Supported	2.68	<.01
Hypothesis2c	Product Safety × Total Cost → User Satisfaction	Not supported	0.76	.45
Hypothesis2d	Product Reliability × Total Cost → User Satisfaction	Not supported	0.39	.69
Hypothesis2e	Product Knowledge × Total Cost → User Satisfaction	Not supported	0.87	.38

user satisfaction. As shown in Table 3, Product Convenience × Total Cost ($\beta = 0.52$, $T = 2.29$, $p = .02 < .05$) and Product Design × Total Cost ($\beta = -0.27$, $T = 2.68$, $p = .008 < .01$) had significant interaction effects on user satisfaction. $\Delta R^2 = .03$ exceed .004 and is significant ($p < .001$), indicating a moderating effect (Barrick, Bradley, Kristof-Brown, & Colbert, 2007). However, Product Safety × Total Cost ($\beta = -0.15$, $T = 0.76$, $p = .45$), Product Reliability × Total Cost ($\beta = -0.08$, $T = 0.39$, $p = .69$), and Product Knowledge × Total Cost ($\beta = -0.19$, $T = 0.87$, $p = .38$) had no significant interaction effects on user satisfaction. This demonstrates that total cost cannot moderate the relationship between product safety (or product reliability, and product knowledge) and user satisfaction.

Discussion

This study not only examines the technical characteristics that affect user satisfaction with ASHP but also explores the contingent role of total cost in the relationship between the technical characteristics and user satisfaction with ASHP. In response, we analyzed the data from a field survey of 256 residents in Beijing that concentrates on promoting the diffusion of ASHP in accordance with the coal to electricity policy. Empirical results are concluded in Table 4.

Technical Characteristics and User Satisfaction

In the case of the technical characteristics of ASHP, product design, product convenience, product reliability, and product knowledge, respectively, have significantly positive effects on user satisfaction. Specifically speaking, product convenience of ASHP might simplify human life and brings much comfort to residents in cold weather. Product design might determine the effective and efficient presentation or development of ASHP components. As an important indicator to measure the degree of which ASHP is reliable, product reliability might be closely related to users' experiences. And, product knowledge can help residents have a better understanding of many aspects of ASHP. Obviously, we believe that these technical characteristics might largely reflect the quality of ASHP. Low quality may detract consumers' confidence in using new RHS (especially those based on cleaner technologies) and result in negative recommendations to other potential users (Salah, Flath, Schuller, Will, & Weinhardt, 2017). Therefore, improving the quality and enhancing technical contents will shape the market potential of cleaner RHS.

However, this study failed to find any significant evidence supporting the assumption that product safety has significant effects on user satisfaction. One possible explanation is that compared with other RHS, the safety characteristic of ASHP has been relatively developed and thus might be not an important concern for residents (Pansari & Kumar, 2017).

Total Cost and User Satisfaction

Our research findings suggested that total cost plays a negative role in user satisfaction. It indicates that the total cost of ASHP is cost-prohibitive for users. In this regard, how to reduce total cost (installation cost, operation cost, and A/S cost) might be a critical challenge for policy makers (Liu, Du, Brown, Zuo, Zhang, Rong, & Mao, 2018). In the case of the moderating effects, total cost was found to weaken the positive effects of product convenience (product design) on user satisfaction. This suggests that balancing the relationship between total cost reduction and product convenience (product design) improvements might be an important factor for the diffusion of ASHP (McPherson, Johnson, & Strubegger, 2018).

Theoretical Contributions

This study provides empirical evidence for consumer behavior theory of households. First, our research may fill a gap in the scholarship by empirically investigating the user satisfaction of the Chinese residential heating sector. User satisfaction is a crucial concept in measuring the quality and popularity of innovative products or services. Our findings may help theoretical researchers have a better understanding of the potential determinants of user satisfaction with cleaner RHS, while traditional theories often argue that the diffusion and success of new products are largely influenced by beliefs and attitudes of individual consumers (Franceschinis, Thiene, Scarpa, Rose, Moretto, & Cavalli, 2017).

Second, we examined the moderating effects of total cost of RHS on the relationship between technical characteristics and user satisfaction. This may contribute to a better understanding of the financial cost impacts on the user's decision-making process in the case of cleaner RHS (Craig & Feng, 2017).

Implications for Conservation

To more effectively speed up the diffusion of cleaner RHS, government should adequately and sufficiently investigate user demand before proposing RHS reform. In addition, due to the higher cost of cleaner energy resources compared with coal, government also needs to provide subsidies to lower costs for newly installed RHS users, which may improve user intention of cleaner RHS (Bjørnstad, 2012). That is because economic consideration is one critical factor that might affect residents' behavior or intention about the adoption of one RHS.

Second, findings may help technology designers and engineers develop more targeted and higher quality RHS. To cope with pollutant emissions and environmental destruction, government has enacted various policies to encourage the development and application of new RHS based on cleaner technologies and renewable resources. In this regard, RHS designers and engineers should have a better understanding of user preferences to improve products' technical functions, such as convenience, design, and reliability (Gadenne, Kennedy, & Mckeiver, 2009).

Third, findings may be useful for marketing managers, highlighting the importance of the word-of-mouth communication in the promotion of cleaner RHS. As an emerging industry in China, RHS manufacturers and marketing practitioners have to confront fierce competition. User's perception on new RHS helps customers choose RHS suppliers in relation to the payment. To realize the diffusion and installation of new RHS, market practitioners should have a comprehensive understanding of user needs and, thus make effective responses accordingly (Michelsen & Madlener, 2017).

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Note

1. "2 + 26" cities means Beijing, Tianjin, Shijiazhuang, Tangshan, Langfang, Baoding, Cangzhou, Hengshui, Xingtai, and Handan (Hebei Province); Taiyuan, Yangquan, Changzhi, and Jincheng (Shanxi Province); Jinan, Zibo, Jining, Dezhou, Liaocheng, Bingzhou, and Heze (Shandong Province); and Zhengzhou, Kaifeng, Anyang, Hebi, Xinxiang, Jiaozuo, and Puyang (Henan Province).

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