Cost-effective subsidy incentives for room air conditioners in China: An analysis based on a McFadden-type discrete choice model

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Abstract

Based on a McFadden-type conditional logit (CL) discrete choice model, this paper estimates the most economic subsidy level (MESL) for room air conditioners (RACs) in China that minimizes the net cost of subsidy per unit of electricity saved. The analysis reveals that, given the current price and efficiency spectrum of RACs in the Chinese market as well as the electricity price and cooling demand of Chinese households, the MESL for RACs in China should be around 60%, which is much higher than the current subsidy level of 5-15%. A sensitivity analysis suggests that the high MESL (60%) is mainly a consequence of relatively low electricity price and household cooling demand in the country. If China's household cooling demand increases further and its electricity price were to rise to a higher level, the MESL for RACs could possibly drop to about 5-15%. As household cooling demand varies among Chinese cities in different climatic zones and at different levels of economic development, the RAC subsidy incentives should be region-specific. With necessary modifications, the method for analysis proposed in this paper can also be applied to other household appliances to prioritize the types of appliances requiring subsidies.

Keywords: Subsidy, Household appliances, Most economic subsidy level, Discrete choice model, China

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1. Introduction

Room air conditioners (RACs) account for about 12-15% of electricity consumption in urban Chinese households (THUBERC, 2013; Zheng et al., 2014a). This share may increase significantly in the near future with rising affluence and rapid improvement in living standards. For examples, this may result in longer RAC use time in summers, lower indoor temperature settings, and higher RAC ownership in households. Considering the heavy dependence of China's power generation on coal (about 78%) (NBSC, 2015), promoting the wider use of efficient RACs is an important means of reducing the nation's enormous emissions of greenhouse gases (GHG) and other air pollutants, such as SO_2, NOx and PM.

The Chinese government has mainly adopted two types of policy incentives to promote the diffusion of efficient RACs, namely energy efficiency standards and labeling (EES&L) schemes and subsidy incentives. The mandatory EES&L scheme for RACs was first established in China in 2005, and along with technology advances the related efficiency standards have been revised (Energy Label, 2016). China's EES&L scheme for RACs was set for three levels, namely Tier-3, Tier-2 and Tier-1 ranging from low to high efficiency. With this mandatory EES&L scheme, RACs with energy efficiency below the stipulated Tier-3 level are prohibited from sale in the Chinese market. Meanwhile consumers are provided with key energy use information of RACs that enable them to make better purchase decisions. However, the purchase of efficient RACs by Chinese consumers has often been found to be hindered by the associated high upfront cost as well as by consumers' income constraints (Watanabe & Kojima, 2016; Zhao et al., 2012).

To address these financial barriers, the Chinese government has designed several rounds of subsidy incentives for efficient RACs to correct for market failures. The earliest RAC subsidy program in China can be traced back to the year of 2009. Two programs were launched in that year. One was called "Replacing the Old with the New". Under this program, a subsidy equivalent to 10% of RAC retail price with a cap of 350 Chinese Yuan/unit was provided to potential consumers once they returned their old RACs to certain recycling stations. The other program was the "Home Appliance to Rural Areas", under which the government exempted 13% of the value added tax (VAT) for selected RAC models if they were sold to rural households (Watanabe & Kojima, 2016). Although these two programs were primarily aimed at expanding domestic sales of household appliances to counter the country's declining exports due to the “2008 global financial crisis”, they did promote the use of efficient RACs in Chinese households to some extent.

In June 2012, the first-ever large-scale subsidy program covering five types of popular household appliance, namely RACs, refrigerators, TVs, washing machines and water heaters, was launched by the Chinese central government (the National Development and Reform Commission). This one-year program had a total budget of about 25.6 billion Chinese Yuan (4 billion USD). The subsidy levels for efficient RACs, namely Tier-1 and Tier-2 models, were set at about 5-7% of their retail prices at that time (see Table 1) (CLASP, 2013). According to the Ministry of Finance of China (MOF, 2013), during that one-year period about 65 million units of these appliances were purchased and this resulted in a total consumer expense of about 250 billion Chinese Yuan. The monthly sales of efficient models of these five appliances increased significantly from 1.6 million units in June 2012 to 7.0 million units in May 2013.

Table 1: China’s 2012-2013 subsidy program for efficient RACs

Cooling capacity (CC)	**Subsidies** (Chinese Yuan/unit)			
	Fixed-Speed RACs		**Viable-Speed RACs**	
	Tier-1	Tier-2	Tier-1	Tier-2
CC ≤ 4,500 W	240	180	300	240
4,500 W < CC ≤ 7,100 W	280	200	350	280
CC > 7,100 W	330	250	400	330

Note: the energy efficiency tiers of RACs are stipulated in the national standards of GB12021.3-2010 (fixed-speed type) and GB21455-2013 (variable-speed type).

(Source: CLASP, 2013)

In November 2015, the Beijing city government announced a separate three-year subsidy program for household appliances, including RACs, TVs and refrigerators, for its jurisdiction, which is effective from November 27, 2015 to November 30, 2018. With a cap of 800 Chinese yuan/unit (about 120 USD/unit), the subsidy levels that are measured as a percentage of appliance retail prices were set at 13% for Tier-1 models and 8% for Tier-2 models for all the types of appliances covered by the policy (Xinhua News, 2015). Inspired by the initiatives of Beijing city, more Chinese cities and provinces are planning to issue their own subsidy incentives for household appliances.

From the above brief retrospective, it is evident that the RAC subsidy levels designed by the Chinese governments have usually been set within the range of 5-15% of products' retail prices. It has been argued that these levels are too low to be effective in practice (TOP10, 2012). A study by Wang et al. (2017) using structural equation modeling to analyze China's 2012-2013 subsidy policy for energy-efficient appliances found that it "has no significant effect on Chinese residents' purchase behavior." Sun et al. (2014a) further suggest that "subsidizing less energy-efficient air conditioners may attract consumers away from more efficient models."

There are also some existing studies on subsidy programs for other household appliances. For example, in a study of China's subsidy programs to biogas digesters (about 50% of the construction cost) for rural households, Sun et al. (2014b) point out that "the net effect of the current subsidy policy on rural household biogas use was near-negligible." By examining China's subsidy program for solar water heaters (SWH), Ma et al. (2014) observe that the applied subsidy level (13% of the purchase cost) is too low, and "has failed to significantly enhance the deployment of SWHs". Galarraga et al. (2013), in a study that assessed the subsidy program for dishwashers in Spain, have argued that such programs could even generate some welfare losses when used in isolation.

This research aims to evaluate such arguments regarding the effectiveness of subsidy programs by using the RACs in China as a case study, and focuses particularly on two research questions. First, how can the cost-effectiveness of subsidy incentives for household appliances (like RACs) be assessed? Second, are the currently set subsidy levels of 5-15% for RACs in China cost-effective when applying the method of analysis proposed here?

Subsidies can help reduce the upfront cost of efficient appliances for consumers, and improve the adoption rates of such appliances (de la Rue du Can et al., 2014). Therefore, to assess the cost-effectiveness of subsidy incentives and identify the most economic subsidy level, it is essential to model consumers purchase decisions for different appliance alternatives. In the U.S., the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) models consumer choices based on a McFadden-type discrete choice model (EIA, 2013a). Although there are some shortcomings of this type of choice model, the McFadden discrete choice model is still widely recognized and used as a standard approach to quantitatively represent consumers' appliance purchase decisions in many globally prominent energy-economy models such as NEMS and MARKAL (Min et al., 2014; Kannan et al., 2007). In this paper, we propose a quantitative method for estimating the most economic subsidy level (MESL) for RACs in China, based on a McFadden-type discrete choice model.

2. Methodology

2.1 McFadden-type discrete choice model

Modeling consumer choices for household appliances has always been a crucial part of residential energy consumption studies. Among the existing binary and multinomial consumer choice models, the McFadden-type discrete choice model has been viewed as the most widely-used one (Train, 2009). In this research, a conditional logit (CL) McFadden-type choice model is adopted to represent consumers' RAC purchase decisions. This model assumes that there is no correlation in unobserved attributes over RAC alternatives, and the utility for each alternative is only related to attributes of that alternative. The standard form of the CL model is presented below (McFadden, 1974; Train, 2009):

$$U_k = Z_k + \varepsilon_k = \beta X_k + \varepsilon_k \qquad (1)$$

$$P_{kt} = \frac{e^{(\beta X_{kt})}}{\sum_{j=1}^{J} e^{(\beta X_{jt})}} \qquad (2)$$

where "U_k" denotes consumer utility from alternative "k"; "Z_k" is the representative utility from alternative "k" given that not all attributes that affect consumer preference are observable; "ε_k" represents unobservable utility of alternative "k" to the analyst, which is assumed to be independent and identically distributed (i.i.d.); "X_k" stands for observable attributes of alternative "k" as well as consumer characteristics; "β" is the scale parameter that accounts for the magnitude of observed consumer utility; "P_{kt}" stands for the probability of a consumer choosing alternative "k" at time "t"; "J" represents the total number of alternatives.

2.2 Methodology for cost-effectiveness analysis of RAC subsidy incentives

The core of applying the conditional logit discrete choice model lies in structuring the consumer utility function. In this study, the utility function used in the U.S. EIA's NEMS model is adopted as follows (EIA, 2013a):

$$X_k = \omega_1 * IC_k + \omega_2 * OC_k \tag{3}$$

$$\frac{\omega_1}{\omega_2} = \frac{r}{1-(1+r)^{-q}} \tag{4}$$

$$AR_k = \frac{e^{\beta X_k}}{\sum_{j=1}^{J} e^{\beta X_j}} \tag{5}$$

where "IC_k" and "OC_k" respectively stand for the initial cost and annual operating cost of alternative "k"; "ω_1" and "ω_2" represent the weights for the two costs, and the ratio of the two weights are determined by the annualizing factor; "r" denotes consumer discount rate; "q" is the typical lifetime of RACs, usually 8-10 years in China; "AR_k" stands for the adoption rate of alternative "k" among consumers; "β" is a scale parameter that represents coefficients of the observable attributes of alternative "k"; "J" represents the total number of RAC alternatives available in the market.

The initial cost and annual operating cost of RACs in China are calculated using Equations 6-7:

$$IC_k = RP_k(1 - SUB_{kL_i}) \tag{6}$$

$$OC_k = \frac{CL}{3.6 \times COP_K} P_e \tag{7}$$

where "RP_k" stands for the average retail price of RAC alternative "k" (USD/unit); "SUB_{kL_i}" is the subsidy level of "L_i" for alternative "k" (a range of 5%-95% is tested in this study); "CL" denotes the cooling load for one unit RAC in Chinese households (MJ/unit·year), which is estimated based on surveyed household cooling load (MJ/m^2·year), average household floor area (m^2/household), and the ownership of RACs (units/household) in Chinese households; "COP_k" stands for the coefficient of performance (W/W) of alternative "k", namely "Energy Efficiency Ratio (EER)" for fixed-speed RACs and "Seasonal Energy Efficiency Ratio (SEER)" for variable-speed RACs; "P_e" represents the electricity price (USD/kWh).

The amount of electricity saved from the implementation of RAC subsidy incentives can then be estimated from Equations 8-10:

$$EC_{base} = \sum_{k=1}^{J} SAC_t * AR_{kL_0} * \frac{CL}{3.6COP_k} \qquad (8)$$

$$EC_{L_i} = \sum_{k=1}^{J} SAC_t * AR_{kL_i} * \frac{CL}{3.6COP_k} \qquad (9)$$

$$ES_{actual,L_i} = \left(EC_{base} - EC_{L_i}\right) * (1 - \varphi) \qquad (10)$$

where "EC_{base}" is the electricity consumption (kWh) of all RACs without subsidy incentives (the subscript "L_0" representing no subsidy incentives); "EC_{L_i}" denotes the electricity consumption (kWh) of all RACs under the subsidy incentive "L_i"; "SAC_t" stands for the total RAC sales (units) at time "t"; "ES_{actual,L_i}" means the actual energy savings (kWh) after considering the rebound effects of the use of efficient RACs by households under the subsidy incentive "L_i"; "φ" denotes the rebound coefficient.

Energy efficiency gains usually lead to a lower price for energy services, which in turn can result in direct rebound effects on energy consumption. For example, people may intentionally use a high-efficiency air conditioner longer than they previously did a low-efficiency one because of lower operating cost. The scale of direct rebound effects can be expressed by a rebound coefficient "φ" (Ouyang et al., 2010), which is defined as the ratio of reduced energy savings to expected (or calculated) energy savings. A higher coefficient "φ" means a larger rebound effect.

The total subsidies ("$TSUB_{L_i}$", USD) provided to RAC buyers under the incentive "L_i" can be calculated by Equation 11:

$$TSUB_{L_i} = \sum_{j=k}^{J} SAC_t * AR_{kL_i} * RP_k * SUB_{kL_i} \qquad (11)$$

Given the values of "ES_{actual,L_i}", "$TSUB_{L_i}$", "PG_e" (i.e., the electricity price gap in China with and without government subsidies in USD/kWh) and "q" (i.e., the typical lifetime of RACs), the cost-effectiveness of the RAC subsidy incentives ("$SPCE_{L_i}$", USD/kWh) can be evaluated as follows:

$$SPCE_{L_i} = {(TSUB_{L_i} - q * ES_{actual,L_i} * PG_e)} \Big/ {q * ES_{actual,L_i}} \qquad (12)$$

It is worth noting that in Equation 12, the net subsidy values are applied. The net subsidies are calculated by excluding the avoided electricity subsidies from the total appliance subsidies provided by governments because of electricity savings.

Using the McFadden-type conditional logit discrete consumer choice model, Equations 3-12 offer a quantitative method of assessing the cost-effectiveness of subsidy incentives for RACs in China. The cost-effectiveness is measured as the net subsidies required for achieving one unit of electricity saved (USD/kWh). This method is also applicable to other household appliances with necessary modifications.

It can be seen that the cost-effectiveness of RAC subsidy incentives is closely related to four key exogenous factors, namely the household cooling load intensity "CL", the electricity price "P_e", the implicit (or subjective) discount rate used by consumers "r", and the rebound coefficient "φ". In this study, a sensitivity analysis was conducted for these four factors (see Section 4.2).

3. Data collection

3.1 Room air conditioner use and market in China

From 2010 to 2013, the annual RAC sales volume in China (mostly split-type) was about 42.8 million units on average (Tencent News, 2014). Of these, around 85% were sold to urban households. The ownership of RACs in Chinese households increased significantly during the recent years (see Figure 1). In 2012, the penetration rates were about 126.8 and 25.4 units per one hundred households in urban and rural China, respectively.

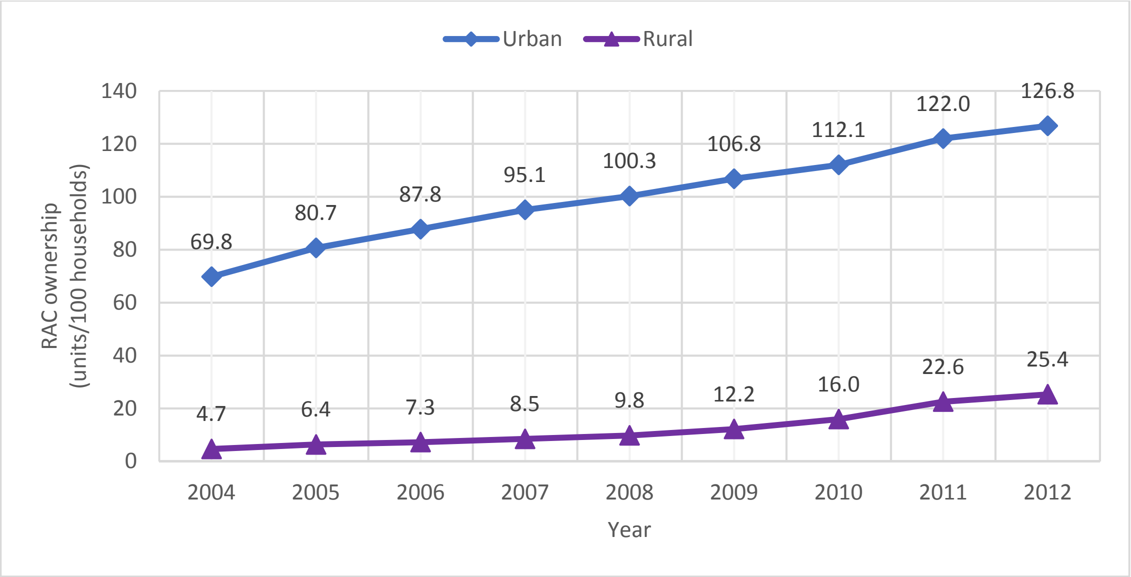


Figure 1: Ownership of RACs in Chinese urban and rural households

(Source: NBSC, 2005-2014)

Owing to unavailability of data on cooling load intensity (MJ/m^2·year) in rural Chinese households, this paper focuses particularly on the substantial urban RAC market in China. According to the China Statistical Yearbook 2014 (NBSC, 2015), the average family size and per capita floor space in urban China was about 2.87 persons/household and 32.7 m^2/capita respectively.

There are currently two basic types of RACs in the Chinese market: fixed-speed air conditioners (FSAC), and variable-speed (i.e., inverter) air conditioners (VSAC). The compressors of FSACs can operate only at a certain single speed no matter what the cooling load levels are. In contrast, the VSAC compressors are able to match system capacity to the actual cooling loads. Accordingly, compared to the FSACs, the VSACs always have relatively higher energy efficiency in operation.

The energy efficiency of FSACs and VSACs are stipulated in the Chinese national standards of GB 12021.3-2010 and GB 21455-2013 respectively (Energy Label, 2016). As stipulated by these standards, the efficiency measurement for FSACs and VSACs are the "Energy Efficiency Ratio (EER)" and "Seasonal Energy Efficiency Ratio (SEER)" respectively. The "EER" is defined as the ratio of output cooling energy to input electrical energy, while the "SEER" is measured in a different way which is the total cooling output divided by total electric energy input during a typical cooling season. The EES&L schemes for RACs in China are shown in Table 2. It is, however, worth noting that the "EER" and "SEER" cannot be directly compared because of the use of different testing methods for them. According to research by Xu & Liao (2008), the "EER" of FSACs would increase by about 0.6 (0.57-0.64) when adopting the "SEER" testing method. To make the "EER" and "SEER" comparable, an efficiency correction of this extent is included when applying the McFadden-type discrete choice model in this paper.

Table 2: Energy efficiency standard and labelling (EES&L) schemes for RACs in China

Model type	**Energy efficiency indicator**	**Energy efficiency tiers**		
		Tier-1	Tier-2	Tier-3
FSAC (CC ≤ 4,500 W)	EER (W/W)	3.6	3.4	3.2
FSAC (4,500 W< CC ≤ 7,100 W)	EER (W/W)	3.5	3.3	3.1
FSAC (7,100 W< CC ≤ 14,000 W)	EER (W/W)	3.4	3.2	3.0
VSAC (CC ≤ 4,500W)	SEER (W/W)	5.4	5.0	4.3
VSAC (4,500 W< CC ≤ 7,100 W)	SEER (W/W)	5.1	4.4	3.9
VSAC (7,100 W< CC ≤ 14,000 W)	SEER (W/W)	4.7	4.0	3.5

Note: CC denotes the cooling capacity.

(Source: National standards of GB12021.3-2010 and GB21455-2013 from Energy Label, 2016)

Due to the relatively small floor space of rooms, which is usually 10-30 m^2 per room, mainly two RACs models are popularly purchased by Chinese households in terms of cooling capacity (CC), namely 1P model (CC=2,200-2,600W) and 1.5P model (CC=3,200-3,600W) (Zheng et al., 2014b). According to the "Chinese Household Energy Consumption Report" by the Renmin University of China (Zheng et al, 2014b), the average cooling capacity per unit RAC in Chinese households is about 3,160W, which is roughly the average of 1P and 1.5P RAC models. Additionally, the energy efficiency (EER or SEER) for 2P, 2.5P and 3P RAC models are generally lower than 1P and 1.5P RACs (see Table 2), and at the same time these are significantly more expensive. Therefore, for the calculations in this paper (i.e., Equations 3-12), excluding 2P, 2.5P and 3P RACs might result in a slight underestimation of the most effective subsidy levels for RACs. This is actually a conservative (or safe) choice for our analysis, and should not substantially affect the findings and conclusions of this paper.

In this study, the average RAC retail prices were obtained from the SUNING website, which is one of the largest online dealers of household appliances in the Chinese market (see Table 3). In total, the retail prices of 1,236 RAC models from thirty-eight domestic and international manufacturers were collected, involving 335 FSAC models (175 1P models and 160 1.5P models) and 901 VSAC models (411 1P models and 490 1.5P models).

Table 3: Average RAC retail prices in the Chinese market

Model type (cooling capacity ≤ 4,500W)	**FSAC**			**VSAC**		
	Tier-3	Tier-2	Tier-1	Tier-3	Tier-2	Tier-1
Average retail prices[1] (Chinese Yuan/unit)	2,053	3,195	5,455	2,938	3,824	5,250
Numbers of available models	288	41	6	431	255	215

Note: [1] The prices were collected as of August 2016, and weighted by 1P and 1.5P RAC models.

(Source: Authors' statistics from SUNING, 2016)

3.2 Space cooling demand in Chinese households

THUBERC (2013) summarizes some surveys of the household cooling load intensity (MJ/m^2 ·year) in different cities from all over China (see Table 4). As most Chinese households use their air conditioners in quite a frugal way, such as turning on RACs for a few hours per day in summers and only in occupied rooms, and setting higher indoor temperatures, the real-world cooling load intensity in China depends not only on local climate conditions, but more significantly on people's use behaviors of RACs (THUBERC, 2013). As shown in Table 4, the household cooling load intensity varies in Chinese cities from about 40-85 MJ/m^2·year. As a comparison, the average cooling intensities in households in the U.S. and Hong Kong are about 173 and 215 MJ/m^2·year respectively (EIA, 2013b; EMSD, 2015), which are 3-4 times the current average level in China.

Table 4: Surveyed household cooling load intensities in urban China

Location		**Cooling load intensities** (MJ/m^2·year)	**Study Year**
Cities	Wuhan	41.0	2004
	Guangzhou	85.3	2003
	Shanghai	46.4	2003
	Hangzhou	68.0	2005
	Xian	44.3	2007
	Beijing	48.6	2012
	Suzhou	54.0	2012
Urban China-average (CN-AVE)		55	
Urban China-high (CN-HIGH)		85	

(Source: THUBERC, 2013)

3.3 Household electricity price in China

Different from the practice in many developed countries, the electricity price for households in China is much lower (usually 40-50% less) than that for industrial and commercial sectors. This implies that the electricity use in Chinese households is, to some extent, subsidized by the government. To promote electricity savings in the residential sector, a tiered pricing of electricity for households has been implemented in China since 2012, with an average rate of about 7.6 US cents/kWh (Zhang & Qin, 2015). Being a regulated sector, power generation in China receives subsidies from the government directly and indirectly in many forms, including tax benefits, lower cost for land use, etc. It has been surmised that the real electricity price might be around 2.1-2.2 times higher, namely about 16.3 US cents/kWh, if all types of government subsidies were removed (Jiang & Tan, 2013; Hong et al., 2013).

China's pledge at the Copenhagen Climate Change Conference (COP15) was to reduce its emission intensity by 40-45% in 2020 relative to 2005. Many studies indicate that China could achieve this target through setting a CO_2 price of \$30/tCO_2 in 2020 (Calvin et al., 2012a; Calvin et al., 2012b). With this proposed climate policy, results of the Asia Modeling Exercise (AME) (2012) estimate that China's electricity price could increase by about 50% in 2020 considering all models involved in the project on average. That is, China's real electricity price (i.e., without government subsidies) for households under this climate policy (\$30/tCO_2 in 2020) could be about 24.5 US cents/kWh, which is quite close to the current electricity price in Japan, namely 26.8 US cents/kWh (the average over 2011-2014) (IEA, 2016).

In this paper, besides the current household electricity price (7.6 US cents/kWh) in China, two other prices were used to conduct a sensitivity analysis, namely the real price in China of 16.3 US cents/kWh (i.e., after removing government subsidies), and the real electricity price under a certain climate policy for achieving China's Copenhagen pledge, which is estimated at about 24.5 US cents/kWh.

3.4 Consumer discount rate

Trading-off between present benefits (or costs) and future ones has constantly been the core of consumer purchase decision-making (Enzler et al., 2014; Hausman J. 1979). This involves the weighting process of intertemporal discounting and risk preference. In many prominent energy-economy models such as NEMS and MARKAL, consumers' technology choices are often quantitatively represented as involving a consumer subjective discount rate (also called individual discount rate), which is usually much higher than the market discount rate, namely the prevailing interest rate on loans (EIA, 2015; Kannan et al., 2007). Although there are arguments for applying subjective discount rates to explain consumers' technology choices, this is still recognized as the most widely-used method in modeling consumers' purchase decisions (Min et al., 2014; Kannan et al., 2007).

There are two basic approaches to estimate consumer discount rates (Min et al., 2014). The first one is by controlled experiment (also referred as task choices or direct inquiry), while the second one is by applying econometric models. Wide heterogeneity in subjective discount rates has been found in previous studies, with rates varying by people's socio-economic status, particularly income (Enzler et al., 2014; Harrison et al., 2002; Green et al., 1996; Hausman, 1979). Higher-income people usually weight future benefits more, implying the use of a lower subjective discount rate by them.

Nonetheless, in practice, to simplify energy-economy models a population-wide subjective discount rate is often applied instead of income-specific discount rates (EIA, 2015; Mundaca & Neij, 2009; Kannan et al., 2007). Moreover, although classic economics assumes that the consumer discount rate represents a stable individual difference variable that "applies to all acts of consumption" (Frederick et al., 2002), some studies indicate that the discount rate relates to specific technologies as well (EIA, 2015; Min et al, 2014; Mau et al, 2008; Dreyfus

& Viscusi, 1995; Ruderman et al., 1987; Doane & Hartman, 1984; Hausman, 1979). Table 5 summarizes some existing literature on consumer discount rates.

Table 5: Consumer discount rates estimated or suggested by existing studies

Models or studies		Objectives/targets	Used or estimated consumer discount rates
Energy-economy models	NEMS (EIA, 2015)	room air conditioner	42%
		central air conditioners	25%
		refrigerators	10%
		natural gas furnaces	15%
	REEPS (Hwang et al., 1994)	calculating the present value of operating cost	40%
	MARKAL (Kannan et al., 2007)	high efficiency household appliances (U.K.)	25%
	MARKAL (Ybema & Kram, 1997)	energy efficiency investment decisions (Netherland)	10-30%
Population-wide consumer discount rates	(Harrison et al., 2002)	Danish	28%
	(Enzler et al., 2014)	Swiss population in two different points of year	26.8% (2007) 27.2% (2011)
Specific equipment	(Hausman, 1979)	room air conditioners	24.1% -26.4%
	(Mau et al., 2008)	hybrid electric vehicles (HEV) and hydrogen fuel cell vehicle (HFCV)	21%-49%
	(Dreyfus & Viscusi, 1995)	automobiles	11%-17%

By reviewing previous studies on consumer discount rates, it is evident that: 1) the rates for RACs might be in the rage of about 20-40% (EIA, 2015; Hausman, 1979); and 2) the population-wide subjective discount rates might be around 30%. The population-wide discount rates are obtained usually from large-scale social survey data, not from controlled experiments on selected small-sized groups. Such controlled experiments often have a bias because of certain sampling issues (Enzler et al., 2014; Harrison et al., 2002). Owing to few studies of consumer discount rates in Chinese cases, in this paper the rate of 30% is used as the reference consumer discount rate for RAC choices in China. Meanwhile a lower and a higher rate, 20% and 40% respectively, are also tested in a sensitivity analysis.

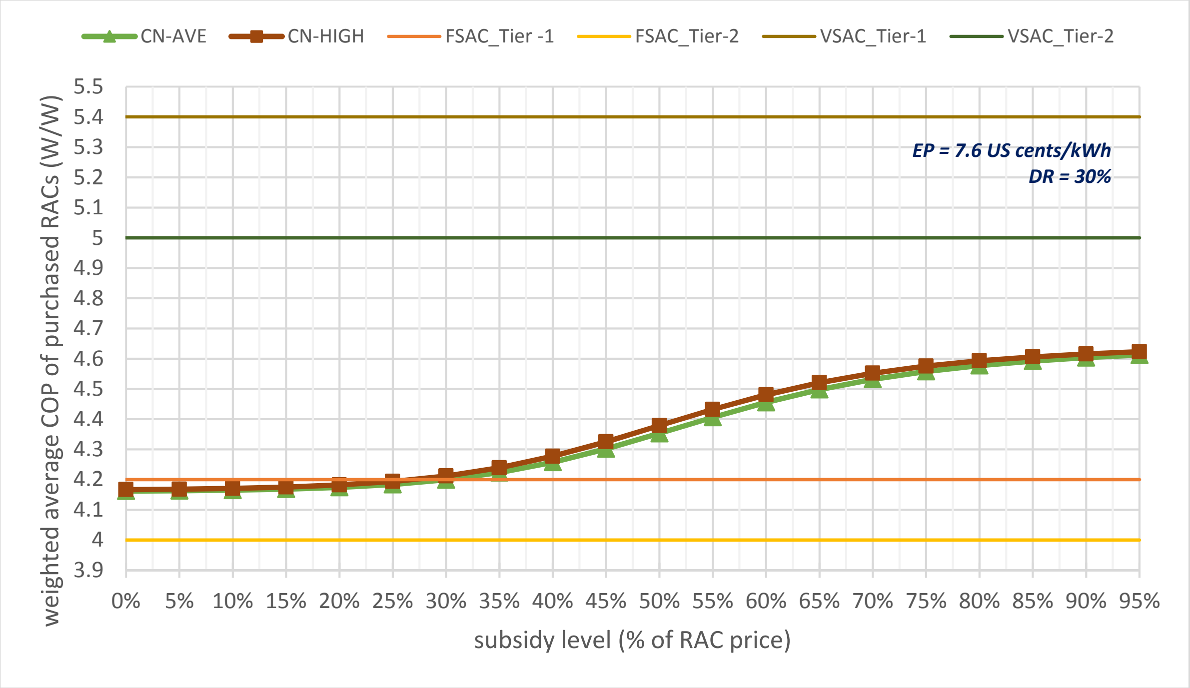
3.5 Rebound effects

The size estimates of rebound effects in household energy consumption vary among end-uses and different studies. For example, the IRGC (2013) estimated that direct rebound effects were about 5-12% for lighting, 0-50% for space cooling, and up to 40% for water heating. In comparison, the ACEEE (2012) reported that the average direct rebound effects for space cooling was about 13%, and it further stated that such effects were likely to be higher in moderate climates where the use of air conditioning is considered optional rather than mandatory. They also reported that there was a small amount of rebound in the case of washing machines (about 5%), and little evidence of rebound effects for water heating and refrigeration. In a review of different studies, the ACCEE (2012) also observed that many estimates of higher rebound effects were primarily based on studies of consumers' response to changes in energy prices, but not to changes in energy efficiency itself. The ACEEE (2012) concluded that direct rebound effects in household energy use tended to be modest, generally 10% or less. As there are few existing studies specifically about rebound effects for China, considering the suggested scales by IRGC (2013) and ACEEE (2012), in this paper four levels of rebound effect (i.e., "φ") for space cooling in Chinese households are examined for a sensitivity analysis, namely no rebound effects (0%), a low level (10%), the reference level (20%) and a high level (50%).

4. Analysis results and discussion

4.1 The most economic subsidy level (MESL)

Based on Equations 3-5, the "weighted average energy efficiency of purchased RACs" in urban China is calculated for different subsidy levels, namely 5%-95% of the retail prices of Tier-1 and Tier-2 RAC models (see Figure 2). As shown in the figure, the efficiency curve is relatively flat at both low and high subsidy levels, but quite steep for the middle range of subsidy levels such as 35-65%. Along with an increase in the subsidy level, the weighted average COP (W/W) of the RAC stock purchased by consumers increases from about 4.17 to 4.62, representing an efficiency gain at the level of difference between that of FSAC Tier-1 and VSAC Tier-2 models. It can be expected that the efficiency curve will shift upward with the rise of electricity price and the growth of cooling load demand.



Note: The COP of FSACs is adjusted be comparable with that of VSACs according to the research (Xu & Liao, 2008).

Figure 2: Weighted average energy efficiency of purchased RACs under different subsidy incentives

With Equations 3-12, the "net cost of subsidy per unit electricity saved" of various RAC subsidy incentives is also calculated (see the results in Figure 3). Figure 3 demonstrates that the policy cost curve is U-shaped. The lowest point on the curve represents the most economic subsidy level (MESL).

With the current cooling demand intensities (CN-AVE, 55 MJ/m^2·year, and CN-HIGH, 85 MJ/m^2·year) and electricity price (7.6 US cents/kWh) in Chinese urban households, the MESL is estimated at about 60%, considering 20% of rebound effects from the use of efficient RACs. It is much higher than the currently applied RAC subsidy levels of 5-15% in the country. The policy cost, namely net subsidies required, at the MESL is only 1.4-2.3 USD/kWh, while it is about 7.5-16.8 USD/kWh at the current subsidy levels in Beijing (i.e., 8-13%), roughly 5-7 times higher than the most economic level.

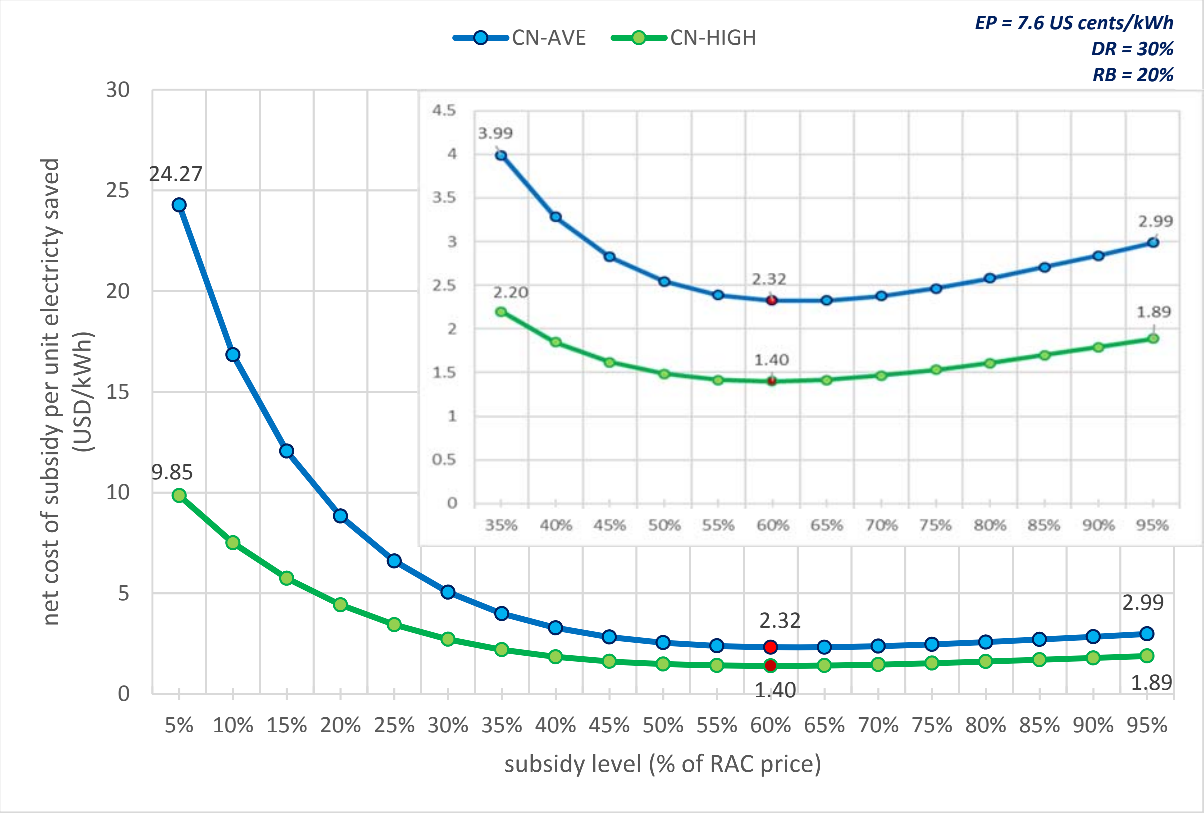


Figure 3: Net subsidies required for one unit of electricity saved under different RAC subsidy incentives in China (EP = 7.6 US cents/kWh; DR = 30%; RB = 20%)

4.2 Sensitivity analysis

In Section 2.2, it has already been mentioned that the household cooling load intensity, electricity price, consumer discount rate and rebound coefficient are four key exogenous variables that affect the cost-effectiveness analysis of RAC subsidy incentives. In this paper, a sensitivity analysis for these four factors is conducted (see Table 6).

Table 6: Summary of the exogenous variables used in sensitivity analysis

Cooling load intensities (MJ/m^2·year)		**Electricity prices** (US cents/kWh)		**Consumer discount rates** (%)		**Rebound effects** (%)	
CN-AVE (China - average) (reference)	55	EP1 (China current price) (reference)	7.6	DR-20% (low level)	20	RB-0% (no rebound effects)	0
CN-HIGH (China - high)	85	EP2 (China price after removing government subsidies)	16.3	DR-30% (reference)	30	RB-10% (low level)	10
US-AVE (U.S. - average)	173	EP3 (China price under a certain climate policy)	24.5	DR-40% (high level)	40	RB-20% (reference)	20
HK-AVE (Hong Kong - average)	215					RB-50% (high level)	50

Note: the exchange rate is 1 USD = 6.6 Chinese Yuan (August 2016).

(Sources: THUBERC, 2013; EIA, 2013b; EMSD, 2015; Zhang & Qin, 2015; Jiang & Tan, 2013; Hong et al., 2013; Calvin et al., 2012a; Calvin et al., 2012b; AME, 2012; EIA, 2015; Hausman, 1979; IRGC, 2013; ACEEE, 2012)

4.2.1 Cooling load intensities

As shown in Table 6, four cooling load intensities were tested in the sensitivity analysis, including two from the U.S. and Hong Kong, which the urban China may reach in the near future with further economic development. The results of a sensitivity analysis under two different electricity prices, namely 7.6 US cents/kWh and 24.5 US cents/kWh, are presented in Figure 4 and 5 respectively.

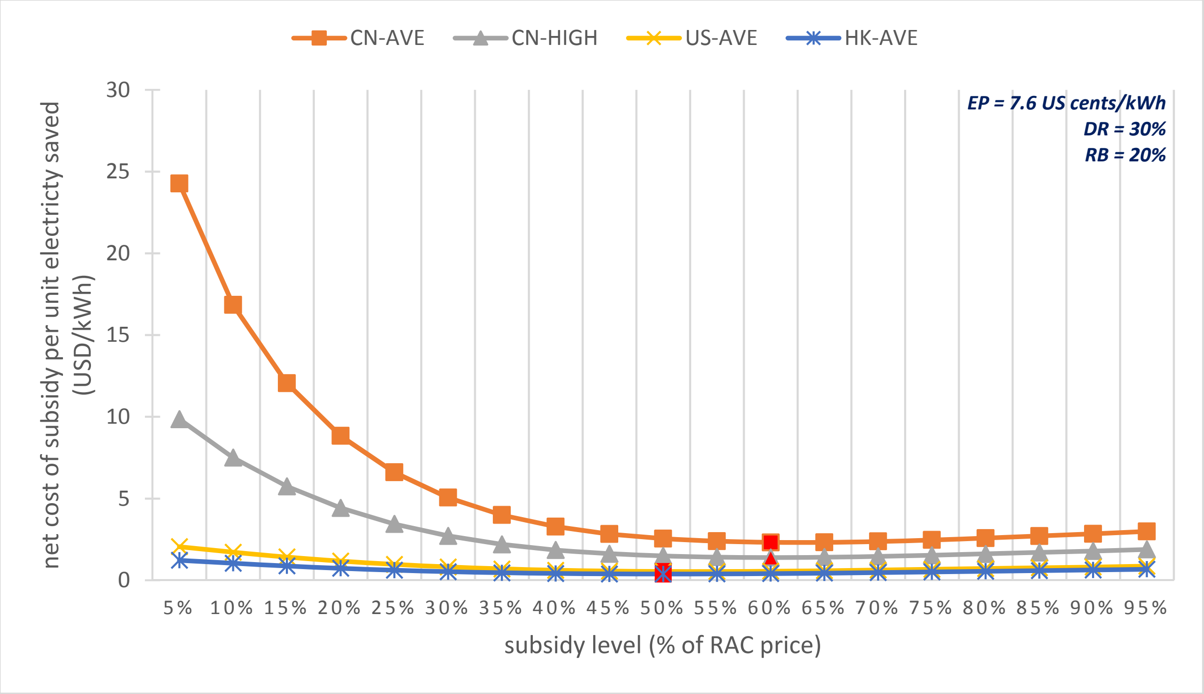


Figure 4: Net subsidies required for one unit of electricity saved under different cooling demand levels (EP = 7.6 US cents/kWh; DR = 30%; RB = 20%)

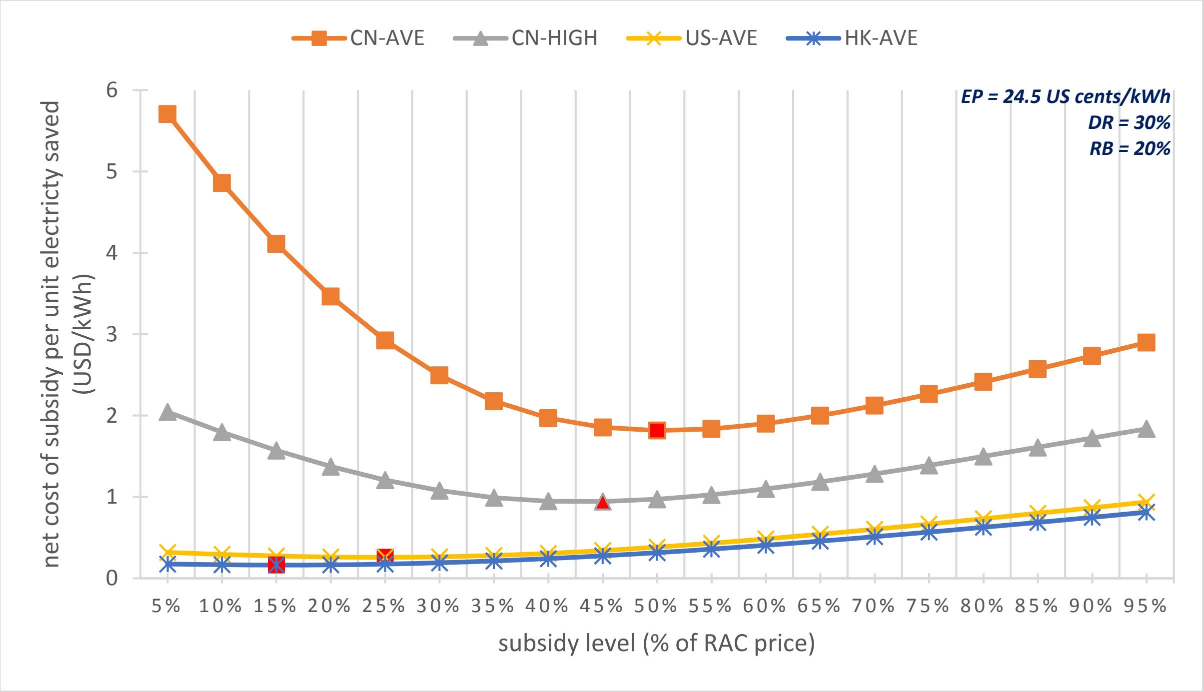


Figure 5: Net subsidies required for one unit of electricity saved under different cooling demand levels (EP = 24.5 US cents/kWh; DR = 30%; RB = 20%)

Several things can be learnt from the analysis. First, the policy cost curve quickly becomes flatter with an increase in household cooling demand at the lower range of subsidy levels (e.g., 5-30%). Second, even if Chinese cities reach the cooling demand intensities of developed regions like the U.S. and Hong Kong, the MESL will drop only slightly from 60% to 50% (see Figure 4), which is still much higher than the levels of 5-15% currently applied in China. Third, at the subsidy level of 10% (i.e., roughly the current Beijing level), the policy cost will significantly drop from 7.5-16.8 USD/kWh to about 1.0-1.7 USD/kWh if China's household cooling demand were to reach the level of the U.S. or Hong Kong while keeping the current electricity price unchanged (see Figure 4). Finally, subsidy levels of 5-15% become the most economic ones only when China's household cooling load demand and electricity price both significantly increase, for example, with cooling demand rising to the level of Hong Kong and a higher electricity rate at a level likely under rigorous climate polices (see Figure 5).

4.2.2 Electricity prices

The sensitivity analysis for electricity price presents a similar trend to that of household cooling demand, that is, the policy cost curve becomes quite flat with an increase in electricity prices at the low rage of subsidy levels (e.g., 5-30%). With the current average cooling load intensity in Chinese households, namely 55 MJ/m^2·year, the MESL will be 60%, 55%, and 50% respectively for the three electricity prices from low to high (see Figure 6). In contrast, if the cooling load intensity in Chinese cities were to reach the current Hong Kong level (i.e., 173 MJ/m^2·year), the MESL will be correspondingly lower at 50%, 35%, and 15% respectively (see Figure 7). In short, both China's current household cooling demand and electricity price are too low to make the current RAC subsidy levels, 5-15%, the most economic.

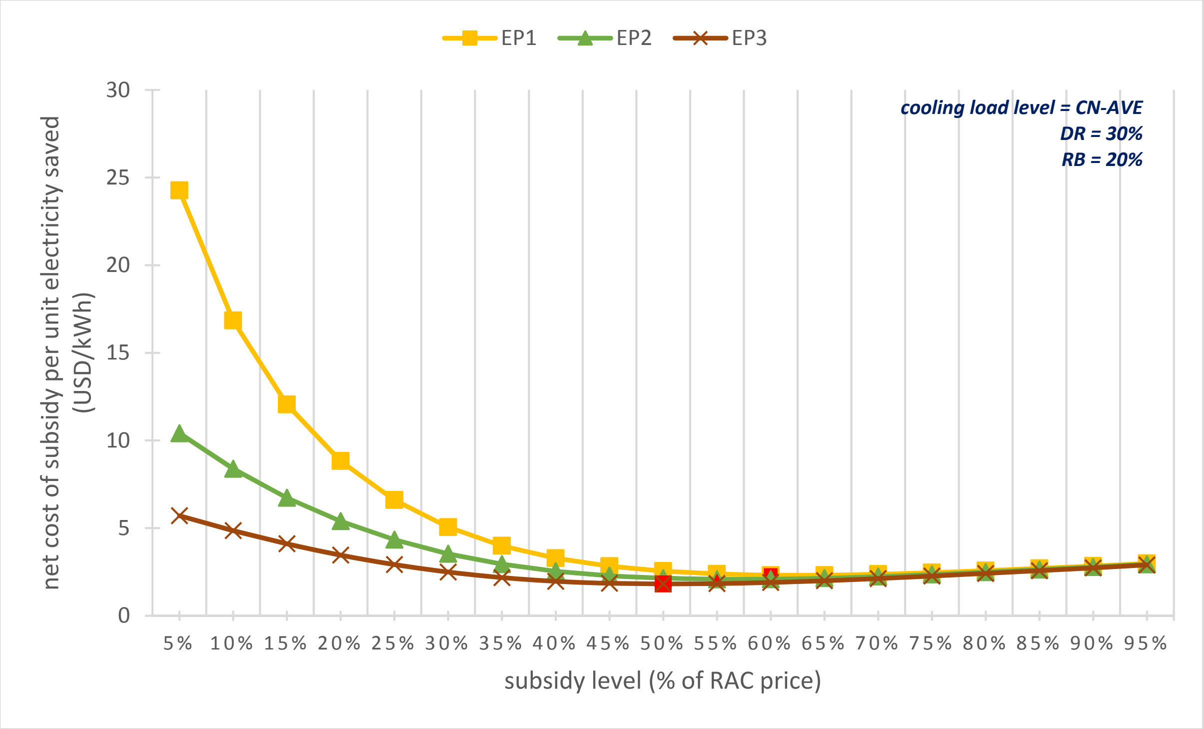


Figure 6: Net subsidies required for one unit of electricity saved under different electricity prices (cooling load level = CN-AVE; DR = 30%; RB = 20%)

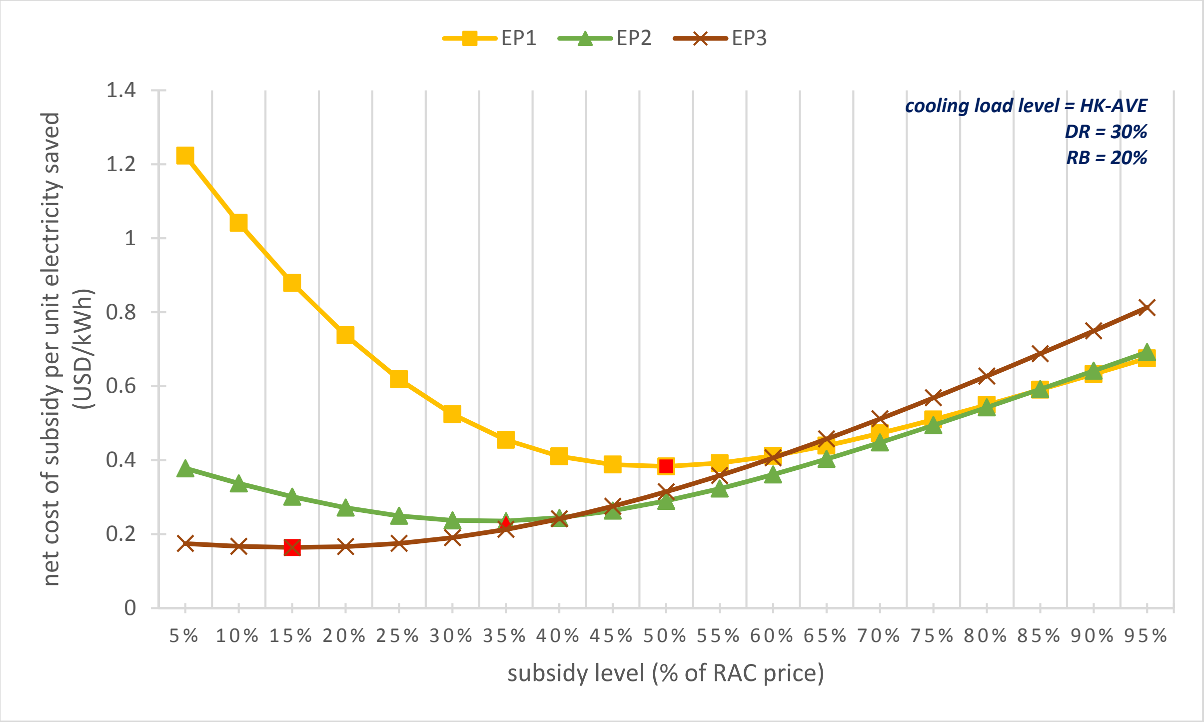


Figure 7: Net subsidies required for one unit of electricity saved under different electricity prices (cooling load level = HK-AVE; DR = 30%; RB = 20%)

4.2.3 Consumer discount rates

The implicit discount rate plays an important role in representing consumers' purchase decisions of household appliances. In this study, based on a broad literature review (see Section 3.4), two consumer discount rates, namely 20% and 40%, are used for a sensitivity analysis along with a reference rate of 30%. The results show that with the current electricity price and average cooling load in Chinese households the MESL are 60%, 60% and 65% respectively for the three discount rates from low to high (see Figure 8). The higher the consumer discount rate used, the higher is the MESL as consumers weigh operating cost benefits from RAC efficiency gains less.

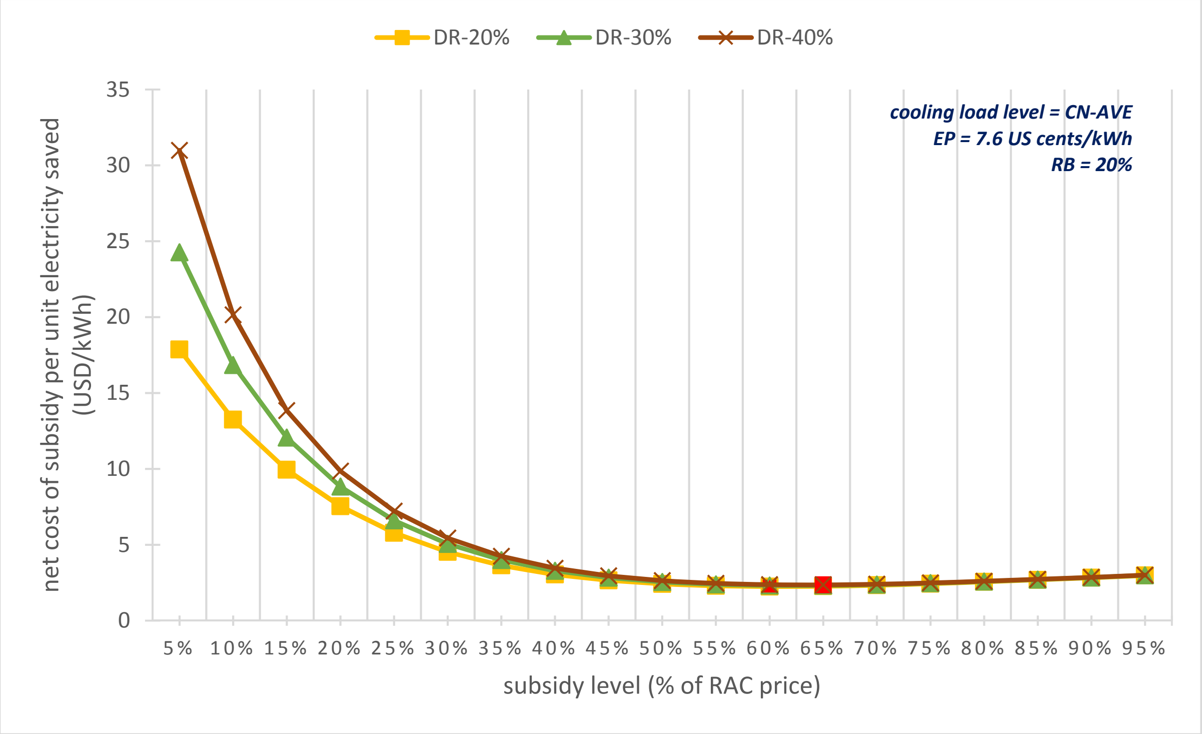


Figure 8: Net subsidies required for one unit of electricity saved under different consumer discount rates (cooling load level = CN-AVE; EP = 7.6 US cents/kWh; RB = 20%)

4.2.4 Rebound effects

Four levels of rebound effects are tested in this study based on a literature review, namely 0%, 10%, 20% and 50%. The results are presented in Figure 9. It is evident that the larger the rebound effect considered, the higher is the policy cost. For example, with the current electricity price and average cooling load intensity in Chinese urban households, the policy cost, namely the net subsidy required for one unit of electricity saved, is estimated at 27.0 USD/kWh, 16.8 USD/kWh, 15.0 USD/kWh and 13.5 USD/kWh respectively for the four levels of rebound effects from high to low, assuming a subsidy level of 10%. Nonetheless, the scale of rebound effects has no substantial effects on the MESL.

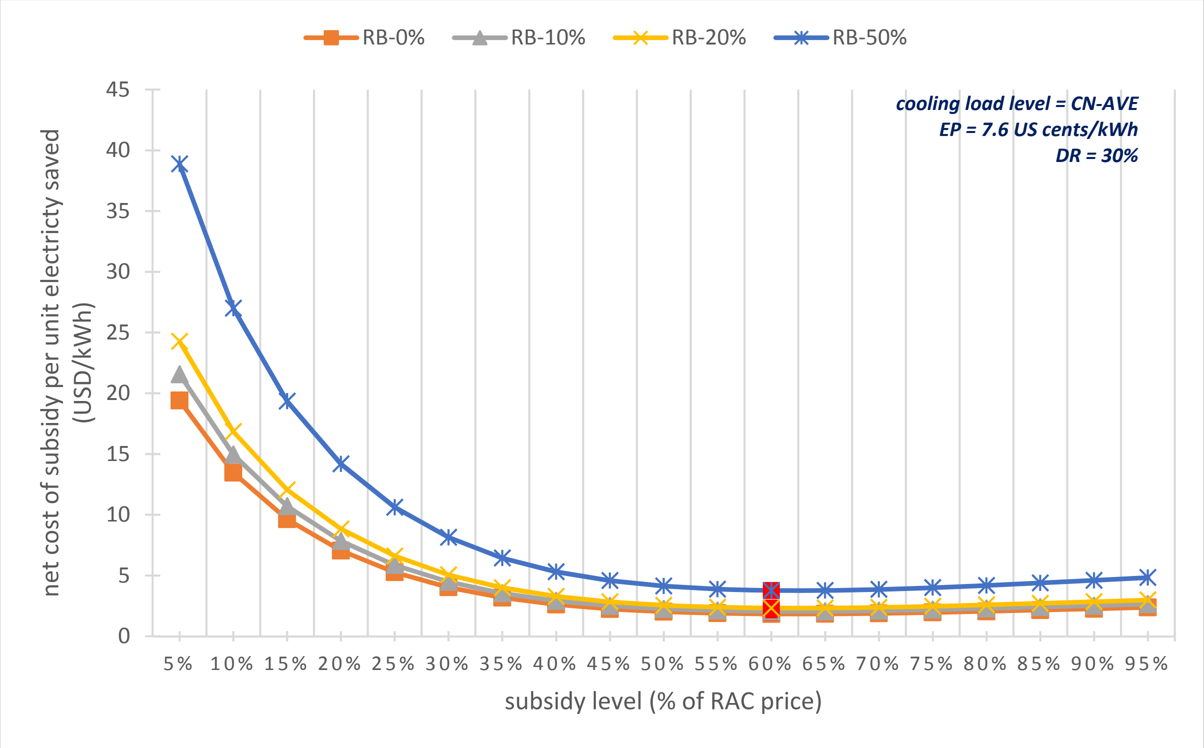


Figure 9: Net subsidies required for one unit of electricity saved under different rebound coefficients (cooling load level = CN-AVE; EP = 7.6 US cents/kWh; DR = 30%)

5. Conclusions and policy implications

The McFadden-type discrete choice model has long been used in many globally prominent energy-economy models, such as NEMS and MARKAL, to represent consumers purchase decisions of household appliances. Based on this type of consumer choice model, this paper explores the cost-effectiveness of subsidy incentives for room air conditioners (RACs) in China. Cost-effectiveness is measured by the amount of net subsidies required for one unit of electricity saved. Net subsidies exclude avoided subsidies to power generation from the subsidies for appliance purchase.

The results of this analysis show that the policy cost curve of subsidy incentives for RACs in China is U-shaped. This implies that the lowest point on the cost curve represents the most economic subsidy level (MESL), measured as a percentage of RAC retail prices. Given the current price and efficiency spectrum of RACs in the Chinese market, as well as the electricity price and cooling demand in Chinese households, this study estimates that the MESL for RACs in China should be around 60%, which is very much higher than the currently adopted subsidy levels of 5-15% by the Chinese governments.

Through conducing a sensitivity analysis, it is also observed that the high MESL for RACs in China is mainly a consequence of the relatively low electricity price and household cooling demand in the country. These two factors largely determine the potential financial benefits to consumers from the use of efficient RACs. The household electricity price in China is only about one-fifth to one-third of that in some energy-efficient economies, such as Japan and Germany. As most Chinese households operate their RACs in quite a frugal way, for examples, turning on RACs for only a few hours per day in summers and for occupied rooms, setting a higher indoor temperature and so on, the average cooling load intensity ($MJ/m^2 \cdot year$) in Chinese households is usually only about one-fourth to one-third that in the U.S. or Hong Kong. The sensitivity analysis shows that if China's household cooling demand were to reach the current U.S. or Hong Kong level and the electricity price were to rise to the current Japan level, the RAC subsidy levels of 5-15% which are currently used in the country would be close to the most economic.

This study also has several policy implications for designing subsidy incentives for household appliances (including RACs) in China. First, as the household cooling demand varies among regions in different climatic zones as well as at different levels of economic development, the RAC subsidy programs should be region-specific in order to be more cost-effective. This implies that subsidy polices for household appliances in developing countries (like China) should not be simply transferred from those in developed countries or regions, such as the EU and the US. Otherwise, the policy cost, namely subsidies required for one unit of electricity saved, might be significantly higher. de la Rue du Can et al. (2014) indicated that "there is no silver bullet for energy efficiency; policy must be developed on a case-by-case basis to respond to market barriers and must embrace local conditions."

Second, the method proposed for the analysis in this paper can be applied to other household appliances, such as refrigerators, TVs and washing machines and so on. By comparing the calculated policy cost curves of different appliances, the appliances to be subsidized can be prioritized in cost-effectiveness given the limited budgets of governments.

Third, there is no “one-size-fits-all” subsidy level for household appliances. The design of a subsidy program for a specific household appliance should be based on a comprehensive evaluation of the price and efficiency spectrum of that appliance’s alternatives available in the market, the electricity price, and household behaviors or patterns of use for that appliance, as that shown in Equations 3-12. In this sense, the currently-implemented household appliance subsidy incentives in Beijing might not be appropriate because a unified subsidy level was set for all types of appliances covered.

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