

Valuation of Environmental Externalities in China's Coal-fired Power Generation: A Latent Class Approach

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Abstract—This paper applies the Latent Class (LC) approach to investigate households' preferences on air quality and study environmental externalities in China's coal-based power sector. We conduct a choice experiment where people are asked to choose among three hypothetical air quality improvement options and status quo characterized by different attributes. Reduction of CO₂ emissions and PM_{2.5} (dust emissions), acid rain (SO₂ and NO_x emissions) and additional electricity bill are presented to respondents as attributes. Our results show that all levels of attributes were statistically significant and positive contributors to welfare. The results implies that the households in China are willing to pay an additional electricity bill for air quality improvement related to coal-based power sector, and willing to pay more for better air quality.

Keywords—coal-based power sector; environmental externalities; choice model; willingness to pay; China

I. INTRODUCTION

Energy crisis and environment pollution has become a severe challenge for China's sustainable development. Reducing environmental disruption during the economic development becomes China's inevitable choice to realize the sustainable development. Quantitative assessment of the external costs to the environment is the important foundation of building environmental regulation policies.

Studies on the environmental externalities in power industry has recently become an actively research topic. One of the common methods is Choice Experiment (CE). Hanley et al [1] pointed out that a main merit of CE is the ability to elicit marginal attribute value of goods or services, therefore, we use CE to quantify respondents' preferences and the willingness to pay (WTP) for the clean production in coal-fired power industry in China. Although the existing researches obtain a lot of conclusions with important meaning, but also have the following issues need to be improved: (1) The results of external environment cost estimation to coal-fired power are not consistent; (2) Empirical researches on the environment externality of China's power generation industry is lack.

The rest of this paper is organized as follows. Section 2 describes our choice experiment design, followed by the

methodology introduction in Section 3. Section 4 presents and discusses the results. We conclude in Section 5.

II. CHOICE EXPERIMENT DESIGN

We employed a face-to-face survey based choice experiment (CE) to elicit the public's preferences for thermal power in China. The set of attributes and their levels were based on extensive literature reviews, national standards such as Ambient Air Quality Standards (GB 3095—2012), and interviews with researchers. A brief description of the attributes and their levels is given in TABLE I.

TABLE I. DESCRIPTION OF THE ATTRIBUTES AND LEVELS.

Attribute	Description	Level
CO ₂	Percentage reduction of CO ₂ emissions	1-5% (low) 6-10% (medium) 11-20% (high)
PM _{2.5}	Air quality level, corresponding to percentage reduction of dust emissions	Excellent air quality good air quality light pollution moderate pollution heavy pollution(status)
Acid rain	Distribution of acid rain, corresponding to percentage reduction of SO ₂ and NO _x	Non-Acid Rain light Acid Rain moderate Acid Rain severe Acid Rain heavy Acid rain
Bill	Increase of the electricity monthly bill	¥0, ¥5, ¥10, ¥15, ¥25

Alternatives were designed by combining the 4 attributes given in TABLE I based on their different attributes levels. 18 choice sets were chosen finally. An example of the choice sets is presented in TABLE II.

TABLE II. AN EXAMPLE OF CHOICE SETS.

Attribute	Plan 1	Plan 2	Plan 3	Status quo
PM _{2.5}	good	Excellent	excellent	Moderate pollution
Acid rain	non	Non	light	heavy
CO ₂	6~10%	1~5%	6~10%	0
Bill	¥25	¥25	¥25	0
Please choose	Plan 1	Plan 2	Plan 3	Status quo

The final questionnaire consisted of three parts: (i) the introduction of investigation purpose; (ii) the CE section; (iii) questions covering socioeconomic data and awareness of environmental issues. Respondents, a total of 600 households, were randomly selected by age, gender and geographical area. Due to non-response and unaccomplished questionnaire, 419 questionnaires were available for analysis yielding 7542 data lines (18 choice sets X 419 questionnaires) for analysis.

III. ECONOMETRIC MODEL

The choice experiments and the following analysis rely on Lancaster's Consumer Theory and McFadden's Random Utility Theory. The indirect utility for respondent n to choose alternative j in choice set t can be expressed mathematically as follows [2]:

$$U_{njt} = V_{njt} + \varepsilon_{njt} \forall j, t \quad (1)$$

where U_{njt} is decomposed into a deterministic component V_{njt} and a stochastic component ε_{njt} . Furthermore, if $U_{nit} > U_{njt}$ for all $i \neq j$ in the choice set t , the respondent will choose alternative i over j . If the distribution of the error term ε_{njt} typically is assumed to be independently and identically distributed (IID) extreme value distribution for all i , the function of choice probability can be expressed as:

$$P_{nit} = \frac{\exp(V_{nit})}{\sum_j \exp(V_{njt})} \quad (2)$$

Eq. (2) describes the multinomial logit (MNL) model, which is the most basic of choice models and advanced models are established on MNL. As a response to the weakness of MNL, the Latent class (LC) model have been developed to better represent heterogeneity in preferences [3]. Latent class is able to capture preference heterogeneity across individuals by simultaneously assigning individuals into behavioral groups or latent segments. For respondent n , who belongs to a particular segment s , the utility of choosing alternative j in choice set t , can be written as:

$$U_{njt|s} = \beta_s X_{njt} + \varepsilon_{njt|s} \quad (3)$$

Here, X_{njt} is a vector of choice attributes and socioeconomic characteristics of respondent n , β_s is a vector of segment-specific parameters to be estimated, and $\varepsilon_{njt|s}$ is an unobserved component, a random error of the utility function. Assuming the iid extreme value distribution in segment, the probability that respondent n , who belongs to segment s , chooses alternative j in choice set t , is:

$$P_{njt|s} = \frac{\exp(\beta_s X_{njt})}{\sum_j \exp(\beta_s X_{njt})} \quad (4)$$

The allocation of respondent n to the segment s is determined by some individual-specific invariant characteristics [4]. The probability of respondent n belonging to segment s can be estimated as a multinomial logit:

$$P_{ns} = \frac{\exp(\theta_s Z_n)}{\sum_{s=1}^S \exp(\theta_s Z_n)} \quad (5)$$

where, θ_s is a segment specific parameter vector and Z_n is a vector the observed characteristic (age, gender, etc.) of respondent n . the S th parameter vector is normalized to zero to secure identification of the model [5]. Given choice probability and the segment probability, the joint probability that respondent n belongs to class s and chooses an alternative j is given by:

$$P_n(i) = \sum_{s=1}^S P_{ns} P_{njt|s} \quad (6)$$

Several indicators has proposed to determine the number of latent segments in Latent Class among existing literatures, such as the minimum Akaike Information Criterion (AIC), and the minimum Bayesian Information Criterion (BIC). BIC is more often used in latent class model because a harsher penalty is imposed by BIC than AIC on the number of parameter and log-likelihood value. Therefore, analyst should take a comprehensive consideration of these criteria, analyst's judgments and model parsimony to guide the final function of latent class model.

WTP measures are calculated as ratios of two parameters. It was important that both parameters (a given attribute and cost) were statistically significant; if not, no meaningful WTP measure can be obtained. According to Hanemann [6], the marginal WTP is specified as:

$$WTP_{attribute} = -(\beta_{attribute} / \beta_{cost}) \quad (7)$$

We estimate the marginal willingness to pay of three attributes, PM2.5, Acid rain and CO2, along with the 95% confidence intervals estimated using the procedure proposed by Krinsky and Robb (1986).

IV. RESULTS

A. General Sample Characteristics

TABLE III summarizes the main socio-economic characteristics of the sample. It can be seen that sixty percent of the sample is male. The respondents is relatively young and well-educated, since about forty-five percent of sample is under 29 years old and sixty-nine percent of respondents is college degree or higher level. Household annual income is mostly below the China average, because our survey was

conducted in city, town and country, where there has a high income inequality. The majority of respondents have kids. Questions about environmental issue were also asked, such as awareness of greenhouse effect. The survey shows about eighty-two of respondents have realized that greenhouse effect is happening.

TABLE III. DESCRIPTIVE STATISTICS.

Variables	Definition and level	Frequency	Percent (%)
Gender	Gender		
	1=male	252	60.14
	0=female	167	39.86
Age	Age		
	1=50 years old and above	34	8.11
	2=between 39~49 years old	106	25.30
	3=between 29~39 years old	91	21.72
	4=else	188	44.86
Education	Education level		
	1=college or higher	287	68.50
	2=high school	75	17.90
	3=else	57	13.60
Income	Household annual income		
	1=above ¥ 50,000	112	26.73
	2=¥ 25,000~¥ 50,000	125	29.83
	3=¥ 10,000~¥ 25,000	104	24.82
	4=else	78	18.62
No kids	Have no kids		
	1=Yes	173	41.29
	0=No	246	58.71
Greenhouse	Awareness of greenhouse effect		
	1=Yes	343	81.86
	0=No	76	18.14

Base: N= 419

B. MNL Estimation Results

Nlogit 5.0 is applied to estimate choice models. The estimation starts with the multinomial logit (MNL) model. The MNL model, only with the choice attributes serves as benchmark for other estimation procedures and the estimation result is presented in TABLE IV.

The results show that the environmental attributes, that is, all levels of improvement in PM2.5 and Acid rain and reduction of CO₂, give positive utility to respondents. The premium ("Bill") was statistically significant at 1% level and negative which means that the probability of paying an extra bill for environment improvement decreased as the premium increased and environment improved.

TABLE IV. ESTIMATED RESULTS OF MNL.

Variable	MNL Coeff (s.e.)
ASC1	-1.693*** (0.321)
ASC2	-1.685*** (0.330)
ASC3	-1.626*** (0.318)
PM2.5(Excellent)	1.164*** (0.201)
PM2.5(Good)	1.173*** (0.155)
PM2.5(Light)	0.430*** (0.147)
Non-Acid rain	1.274*** (.269)
Light Acid rain	0.932*** (.253)
Moderate Acid rain	0.753*** (.275)
CO ₂ reduction (11%~20%)	0.732*** (0.147)
CO ₂ reduction (6%~10%)	0.663*** (0.126)
CO ₂ reduction (1%~5%)	0.403*** (0.123)
BILL	-0.071*** (0.011)
Model summary statistics	
Log-likelihood	-3409.820
Restricted log-likelihood	
McFadden Pseudo R ²	
AIC/N	2.727
BIC/N	2.751
Number of respondents	419
Number of observations	2514

C. LC Estimation Results

TABLE V presents the AIC, BIC, LL value and McFadden Pseudo R² for LC model from two to six segments. The results show that as the number of segments increases, the AIC value decrease while BIC reaches the lowest point at three-segment solution, and LL value and McFadden Pseudo R² increase. Since BIC penalizes harsher on number of parameters and LL values than AIC and the improvement of LL value and McFadden Pseudo R² is relatively strong from 2 to 3 classes, the LC model with three segments is opted for rest of analysis of LC model.

The result of three-class LC model is reported in TABLE VI, all the membership coefficients for segment 3 are normalized to zero, and the other coefficients are interpreted in relation to segment 3. The result indicates that compared to segment 3, there are more male respondents, less respondent with "college or higher" education level, and more respondent with kids in segment 1. For segment 2, all the "Income" coefficients are significant positive, suggesting respondents in segment 2 had a higher income than that in segment 3. Considering the positive sign of "No kids" in segment 2, there are more respondents without kids in segment 2.

As for the utility function, the respondents in segment 1 were characterized by positive and significant coefficients for "PM2.5 (Light)", "CO₂ reduction (11%~20%)" and "CO₂ reduction (6%~10%)", while for the other attributes coefficients are not significant. This implied that respondents in segment 1 only cared about improvement in PM2.5 and CO₂ reduction. Meanwhile, the respondents in segment 2 and 3 concern about all levels of environmental improvement, but respondents in segment 3 also care the premium, when the premium increases, they become unwillingness to pay. The results also show that 27.5 percentage of respondents belong to segment 1, 21.7 percentage belong to segment 2, and 50.8 percentage to segment 3.

TABLE V. THE VALUE OF AIC AND BIC FOR LATENT CLASS MODELS.

No. of segments	AIC/N	BIC/N	LL	McFadden Pseudo R ²
2	2.176	2.264	-2692.731	0.226
3	2.067	2.213	-2530.801	0.273
4	2.015	2.220	-2441.419	0.298
5	1.983	2.245	-2375.504	0.317
6	1.978	2.298	-2344.327	0.326

TABLE VI. THE RESULTS OF LATENT CLASS MODEL.

Variable	LCM (3 classes)		
	Class 1	Class 2	Class 3
Utility function			
ASC1	-4.608**(1.871)	-4.483**(2.032)	-0.756(0.582)
ASC2	-5.038*** (1.887)	-3.909* (2.066)	-0.892(0.599)
ASC3	-4.441** (1.904)	-3.342* (2.014)	-1.291** (0.605)
PM2.5(Excellent)	0.383(0.828)	4.560*** (1.124)	1.880*** (0.305)
PM2.5(Good)	0.858(0.640)	4.180*** (1.064)	1.813*** (0.230)
PM2.5(Light)	1.259*(0.691)	2.136** (0.848)	0.756*** (0.196)
Non-Acid rain	-0.271(0.840)	4.111*** (1.120)	2.105*** (0.416)
Light Acid rain	-0.945(0.777)	3.630*** (1.197)	1.762*** (0.396)
Moderate Acid rain	-0.084(0.851)	3.223*** (1.177)	1.153*** (0.435)
CO2 reduction (11%~20%)	2.894** (1.462)	2.368*** (0.894)	1.801*** (0.294)
CO2 reduction (6%~10%)	2.783** (1.389)	2.272*** (0.821)	1.752*** (0.269)
CO2 reduction (1%~5%)	1.784(1.292)	1.942** (0.787)	1.293*** (0.244)
BILL	-0.066(0.044)	-0.019(0.044)	-0.158*** (0.021)
Average Class Probabilities	0.275	0.217	0.508
Class membership function			
Constant	0.578(0.630)	-5.965*** (1.644)	
Male	0.552*(0.298)	-0.449(0.415)	
Age(>50)	-0.812(0.677)	0.800(1.060)	
Age(39~49)	-0.700(0.552)	0.382(0.805)	
Age(29~39)	0.147(0.518)	0.154(0.728)	
College or higher	-0.715*(0.390)	1.229(0.865)	
High school	-0.319(0.436)	0.769(0.988)	
Income(>50000)	0.051(0.483)	3.975*** (1.116)	
Income(25000~50000)	-0.309(0.450)	4.068*** (1.193)	
Income(10000~25000)	-0.425(0.454)	2.445** (1.160)	
No kids	-1.508*** (0.554)	1.334* (0.726)	
Greenhouse	-0.173(0.364)	0.186(0.509)	
Model summary statistics			
Log-likelihood	-2530.801		
Restricted log-likelihood	-3479.599		
McFadden Pseudo R ²	0.273		
AIC/N	2.067		
BIC/N	2.213		
Number of respondents	419		
Number of observations	2514		

D. Willingness to Pay Analysis

The estimated marginal WTP values for the attributes of MNL and LC models are presented in TABLE VII. The Krinsky and Robb (1986) bootstrapping procedure using 2,000 draws has been applied to calculate the standard errors.

TABLE VII. MARGINAL WTP VALUES FOR MNL AND LC, 95% CONFIDENCE INTERVAL.

	MNL	LC		
		Class1	Class2	Class3
PM2.5(Excellent)	16.463*** (12.148,20.778)	5.810 (-15.022,26.643)	241.078 (-841.387,1323.543)	11.909*** (9.060,14.757)
PM2.5(Good)	16.588*** (12.044,21.131)	13.006 (-4.681,30.693)	220.981 (-781.655,1223.617)	11.4856*** (8.954,14.017)
PM2.5(Light)	16.082*** (1.944,10.220)	19.082 (-7.748,45.913)	112.890 (-422.428,648.209)	4.786*** (2.455,7.117)
Non-Acid rain	18.020*** (11.088,24.952)	-4.113 (-32.314,24.089)	217.326 (-747.995,1182.648)	13.333*** (8.597,18.068)
Light Acid rain	13.188*** (6.017,20.359)	-14.327 (-47.494,18.839)	191.872 (-685.617,1069.361)	11.159*** (6.291,16.027)
Moderate Acid rain	10.656*** (2.956,18.355)	-1.269 (-26.978,24.439)	170.375 (-610.154,950.904)	7.302*** (2.009,12.596)
CO2 reduction (11%~20%)	10.356*** (5.291,15.421)	43.863 (-22.412,110.138)	125.202 (-469.433,719.836)	11.4072*** (6.878,15.937)
CO2 reduction (6%~10%)	9.375*** (4.713,14.036)	42.176 (-23.269,107.622)	120.089 (-460.634,700.812)	11.096*** (6.943,15.249)
CO2 reduction (1%~5%)	5.695*** (1.447,9.942)	27.039 (-24.658,78.735)	102.662 (-397.834,603.158)	8.190*** (4.402,11.977)

***, ** and * indicates significant at 1% level, 5% level and 10% level respectively.

The results also indicate that the marginal WTP per household for PM2.5 improving from moderate pollution (status quo) to excellent air quality is 16.463 CNY per month, for acid rain from severe acid rain to non-acid rain is 18.02 CNY per month and for CO2 from non-emission reduction to high emission reduction is 10.36 CNY per month. For PM2.5, the value of WTP for PM2.5 (excellent) and PM2.5 (good) were almost the same, and higher than PM2.5 (light); For acid rain, the value of WTP for non-acid rain is the highest, higher than light acid rain and moderate acid rain; For CO2 reduction, the value of WTP for reduction (11%~20%) is higher than the others. These results indicate that respondents are willing to pay more for better environmental condition.

V. CONCLUSION

The main objective of this study was to assess the external environmental cost of coal-fired power plant using latent class approach. The results of MNL and LC indicate that, respondents' willingness to pay for improving environmental externality of coal-based power sector is significantly positive and respondent are willing to pay more for better environmental condition.

In our analysis we focus on quantifying willingness to pay for environmental improvement. The results may contribute to electricity bill and policy maker.

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