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Residential preferences for stable electricity supply and a reduction in air pollution risk: A benefit transfer study using choice modeling in China

Abstract This paper uses choice modeling surveys from the Chinese cities of Jiujiang, Jiangxi Province, and Changsha, Hunan Province, to identify residential preferences for simultaneously increasing the stability of the electricity supply and decreasing the health risks from air pollution. Air pollution in China is mainly attributable to externalities associated with the electricity supply. We employ a contingent ranking approach as our choice modeling method and test for the transfer of benefits for these preferences between the two sites. The original benefit estimates indicate that the implicit price for reducing the number of power breakdowns is about $\mathrm{RMB83/(times \times year \times household)}$ in Jiujiang and $\mathrm{RMB78/(times \times year \times household)}$ in Changsha, while the implicit price for reducing the duration of power breakdowns is statistically zero in Jiujiang and $\mathrm{RMB71/(hours \times year \times household)}$ in Changsha. From the alternative perspective, we estimate that the annualized value of the statistical lifetime risk of cancer caused by air pollution over a 70-year period is $\mathrm{RMB50{,}844/year}$ in Jiujiang and $\mathrm{RMB67{,}146/year}$ in Changsha. This suggests that we do not reject benefit transferability based on the implicit price of the number of power breakdowns, but do reject it based on the number of deaths from cancer caused by air pollution.

Keywords Power plants · Power breakdowns · Air pollution · Choice modeling · Benefit transfer

JEL codes: Q41; Q53

1 Introduction

The demand for electricity in China has increased sharply in recent years. According to the Tenth Five-Year Plan (2001–05), the Chinese government expected electricity demand to grow by 5% annually, whereas in reality it increased by 12.9% (Japan Electric Power Information Center, Inc. 2006). Maintaining a stable power supply to meet accelerating energy consumption in China is essential for sustaining economic development. However, a recent succession of large-scale power breakdowns in China has had adverse consequences for both the economy and citizens (see, among others, Andrews-Speed et al. 1999; Steenhof and Fulton 2007; Wang 2007). For example, during the summer of 2005, the power supply was restricted in 26 of China's 30 mainland provinces and provincial-level municipalities and cities because of insufficient supply (Japan Electric Power Information Center, Inc. 2006). The potential loss of national income caused by similar power breakdowns in 1994 (Yang and Yu 1996) was estimated at 140–470 million renminbi (RMB) in 1990 prices. Similarly, Yuan et al. (2007) showed that electricity consumption unilaterally caused economic growth, and that the energy sector and the whole economy would be unsustainable under the existing economic structure. Using data from Shanghai, Sun et al. (2006) concluded that the outage cost of the electricity supply is much higher than the average cost of the supplied electric energy. This cumulative evidence demonstrates that preventing future power breakdowns and ensuring a reliable power supply constitute important policy items for China.

Maintaining a balance between electricity supply and demand in China requires power generation to increase in volume. Increasing thermal power generation from coal is one of the more promising approaches because China has large coal stocks relative to its oil and natural gas reserves. In 2001, thermal power generation accounted for 81.2% of total power generation, and 95% of thermal power generation was dependent on coal power generation (Zhu et al. 2005). However, as coal power plants also emit air pollutants, such as carbon dioxide, nitrogen oxides (NO_X), sulfur oxides (SO_X; mostly sulfur dioxide (SO_2)), and particulate matter (PM), including $PM_{2.5}$ and PM_{10}, policy is also required to encourage a decrease in these pollutants. The main pollutants from coal power plants are PM and SO_2 (Xue et al. 2005). Nationally, China's thermal power plants discharged on average 41% of China's SO_2 emissions in 2004 (Japan Electric Power Information Center, Inc. 2006). Furthermore, PM from coal power generation accounts for about one-third of the total discharge by China's industrial sector (Zhu et al. 2005). At the same time, coal power plants have fallen behind in terms of adopting countermeasures to decrease pollutants. For example, just 12.6% of all coal power generation units in China have installed desulfurization equipment (Horii 2008). Therefore, policy in China should aim to ensure a simultaneous increase in the reliability of the power supply and the better adoption of countermeasures for pollutants associated with the power supply.

From a policy perspective, it is vital to evaluate the benefits of maintaining a reliable power supply while minimizing the level of pollutants. When evaluating those benefits, it is important to consider not only residential consumer surplus in China but also, inevitably, the effect on producer surplus. It is also reasonable to assume that Chinese residents face a trade-off between a more stable electricity supply and a reduced risk of air pollution associated primarily with electricity supply causing serious health problems. Thus, when conducting a cost–benefit analysis (CBA) of this trade-off, it is necessary to capture the preference structure for Chinese residents. Nevertheless, although value estimates are a prerequisite for the implementation of CBA for policy decisions such as these, benefit assessments in developing countries are generally insufficient because of a lack of suitable financial and human resources, at least when compared with those available in developed countries. Accordingly, when estimating these values, we should not only address the conventional investigation of policy benefits but also consider alternative methods.

In the conventional investigation of residential benefits, choice modeling (CM) is generally appropriate because it is able to assess several policy variables at the same time (Louviere et al. 2000). CM usually involves choosing preferred types through, say, a choice experiment (CE), or ranking different types, using perhaps contingent ranking (CR), in such a way that clarifies the preferences for multiattribute options. For instance, in China, Zhai and Suzuki (2008) conducted a CE on environmental management and regional development in coastal areas. However, because the opportunity and timing of such surveys in China tend to be limited, CR appears more appropriate because of its capability to extract a richer set of information.

As for an alternative method, benefit transfer (BT), which estimates benefits using the results of previous studies, could be one of the more promising approaches for developing countries. Because BT uses previously estimated benefits, we can measure benefits quickly and at lower cost. In addition, CM is consistent with BT analysis in environmental valuation studies (Morrison et al. 2002; Morrison and Bergland 2006) because CM is sufficiently flexible to adjust the values of the policy instruments, such as the degree of health risk reduction. Therefore, in this study, we conduct both CM surveys and a BT study on the economic evaluation in China of a stable electricity supply and a reduction in health risk related to local air pollution. To ensure sufficient observations from the surveyed respondents, we employ CR.

The remainder of the paper is organized as follows. Section 2 summarizes the previous research on the stability of energy supplies, local air pollution risk reduction, and benefit transfers. Section 3 describes our survey design and details the chosen econometric methods. Section 4 provides the estimated results, which we discuss in Sect. 5. Finally, in Sect. 6, we present our concluding remarks and present several topics for future research.

2 Literature review

2.1 Stability of energy supply and reduction in local air pollution risk

A number of studies have examined the outage cost of the electricity supply. Among the studies using CBA, Liu et al. (1997) conducted a CBA of demand-side management where a public utility sought to overcome, among other things, electricity supply shortages, peak and off-peak loads in power demand, and serious urban environmental pollution. They demonstrated the cost effectiveness of management in terms of the potential for electricity saving and avoided peak capacity. Su and Teng (2007) also used a CBA framework that quantified the costs of the failure of electric distribution networks in Tai-Chung, Taiwan, comprising customer outage costs and utility costs associated with reduced energy revenue. They established that the automation of electricity distribution was appropriate for the studied area because of the high customer outage costs.

Among the valuation studies, Matsukawa and Fujii (1994) investigated the preferences of large-scale computer users in Japan for a reliable power supply. Employing data on the choice of backup equipment, such as an uninterruptible power supply, they concluded that the outage costs were higher for the financial and communications sectors than for other sectors. In Sweden, Söderberg (2008) considered the willingness to pay (WTP) of distribution utilities and industrial customers for a reduction in electricity outages, and Carlsson and Martinsson (2007, 2008) investigated WTP in households. Using as attributes the duration of announced and unannounced outages, voltage stability, perceived customer service and price, Söderberg (2008) also employed a CE; Carlsson and Martinsson (2008) applied a CE to the number and duration of outages; and Carlsson and Martinsson (2007) used two open-ended contingent valuation method (CVM) questions on averting planned and unplanned electric outages.

The literature thus shows that electricity outage cost, or the stability of the electricity supply, is one of the major concerns in energy policy. Because electricity investments tend to be large, it is natural to cite cost effectiveness as another major concern. Furthermore, when demonstrating cost effectiveness with CBA, reliable benefit and cost estimates are required. In the evaluation of residential preferences in China, a CE or CM is likely to prove more suitable than many other methodologies, such as those in Matsukawa and Fujii (1994), mainly because of data availability and other methodological improvements.[1]

Much of the existing research also considers the externalities associated with energy production. For instance, addressing local air pollution risk as one particular externality, Xue et al. (2005) simulated the spatial distribution of incremental SO_2 and PM_{10} resulting from the West–East Power Transmission Project in China. In other work, Rafaj and Kypreos (2007) concluded that the internalization of the external cost into the price of electricity increased the competitiveness of non-fossil fuel generation sources and fossil fuel power plants with emission controls. Given the results of these studies and others, such as Bollen et al. (2009), it is clear that externalities associated with the electricity supply constitute yet another major concern in the formulation of energy policy.

Few valuation studies of local air pollution explicitly concentrate on the energy externalities. Exceptions include Wang and Mullahy (2006), who applied an open-ended CVM to estimate the WTP for a reduction in local air pollution in Chongqing, China, and Dziegielewska and Mendelsohn (2005), who employed dichotomous choice CVM questions to evaluate the harmonization of Polish and European Union (EU) air pollution standards. In other work, Hammitt and Zhou (2006) employed a double-bounded dichotomous choice CVM on the reduction in the risk of chronic bronchitis and mortality associated with air pollution in Beijing, Anqing, and rural areas around Anqing in China. Similarly, Aunan et al. (1998) conducted a CBA of the reduction in air pollution risk for health and the environment in Hungary using BT with unit value estimates from the western EU. Finally, Wang and Mauzerall (2006) demonstrated that it was beneficial to alleviate

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[1] Matsukawa and Fujii (1994) examined the choice of backup equipment by large-scale computer users. In terms of household preferences in China, it is reasonable to view this choice as unrealistic given the relatively small scale of household electricity usage.

air pollution in eastern China, mostly by employing the results of valuation studies previously conducted in the United States.

To our best knowledge, no previous study, in either the developed or the developing world, has simultaneously addressed residential preferences for the stability of the electricity supply and the reduction in local air pollution risk by explicitly defining the latter as an electricity supply externality. In this context, our chosen CR approach serves to fill a serious omission in the energy literature.

2.2 Benefit transfer

Discussion of BT methods appears in Water Resources Research 28(3), 1992, and in a synthesis of previous work in Ecological Economics 60(2), 2006. Recent developments in BT studies are also reviewed in Navrud and Ready (2007), in a special issue of the American Journal of Agricultural Economics 91(5), 2009, and several BT studies appear together in the Journal of Forest Economics 15, 2009. Overall, existing studies have focused on whether BT analysis can achieve reliable results and whether certain processes can improve it. Despite this, care should be taken with its application in that the estimated benefits potentially move between different population groups, that is, the respondents in the study site from where the estimates originate, and those in the policy site, where they are applied (Desvousges et al. 1992).

There are an increasing number of BT studies using CM (Rolfe and Bennett 2006). For example, Colombo et al. (2007) analyzed a CE using conditional logit (CL) and random parameter logit (RPL) models to incorporate CE data into the BT analysis. They concluded that RPL helped to mitigate transfer errors more than CL did, which suggests a statistical advantage for RPL, possibly because of the inclusion of preference heterogeneity. Johnston and Duke (2010) investigated BT using a CE for farmland management, and recommended that BT practitioners search widely for the adjusted transfer given population characteristics. Thus, it is possible to produce reliable benefit estimates from BT by employing the improved accuracy of the analysis, comprising both the inclusion of preference heterogeneity and the use of population characteristics as adjustment factors.

There are also several previous studies on BT analysis in developing countries. For example, Tuan et al. (2009) applied BT analysis to historical temples in Thailand and Vietnam, and tested its validity and reliability by comparing it with the results of dissonance-minimizing CVM. In other work, Zhai and Suzuki (2009) examined international BT between coastal residents in China, Japan, and South Korea. They conducted identical CE surveys between sites, which examined the issues of improving the coastal environment, reducing the frequency of natural disasters, and promoting coastal usage, alongside annual additional expense per capita as the price attribute. However, to the best of our knowledge, no previous studies have considered BT with regard to simultaneously increasing the stability of electricity supply and decreasing any externalities of electricity production. Therefore, our approach serves as another BT case study. To obtain results that are more rigorous, we employ RPL as the estimation procedure and respondent characteristics as adjustment factors.

3 Data and methods

3.1 Survey design

We conducted our surveys in the Chinese cities of Jiujiang in Jiangxi Province and Changsha in Hunan Province. These sites are well suited to BT analysis because both regions have recently had power plants constructed to improve electricity supply to meet the increase in electricity demand and because the construction projects in both aimed to minimize any health risks related to local air pollution.[2] In addition, the two sites are similar in being inland Chinese cities with comparable populations, although they do differ with regard to the existence of coal-fired power plants.[3] In the heart of Jiujiang is a single 1,350 megawatt coal-fired thermal power plant (the Jiujiang Jiangxi Thermal Power Plant) (Japan Electric Power Information Center, Inc. 2006). By contrast, Changsha has no large coal-fired power plants, although Hunan Province has rich sources of hydropower. Therefore, compared with the residents of Changsha, the residents of Jiujiang may perceive a greater risk of pollutants from power plants. We decided to designate Jiujiang as the study site and Changsha as the policy site because residents in Jiujiang are arguably more sensitive to the risks of local air pollution. We administered the surveys in Jiujiang during March 5–12, 2008, and in Changsha during March 25–27, 2008; the closeness of the survey timing enabled us to eliminate any time-trend effects. As detailed in Table 1, we obtained 225 useful observations from 285 total responses in Jiujiang (78.9%) and 197 observations from 297 total responses in Changsha (66.3%).

<**Table 1** Demographic statistics>

We used in-person survey data to investigate the preferences for electricity supply and air-quality improvements in China. We used CR to clarify preferences for a scheme involving

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[2] The Japanese Bank for International Cooperation has supported a number of official development assistance (ODA) loan projects in China, including the construction of the coal-fired thermal power plant in Jiujiang and a hydropower plant in the western region of Hunan Province. The former included funding for special equipment aimed at reducing the emissions of certain pollutants (including NO_x, SO_x, and PM10) associated with the power plant, and the latter funding was used to construct a cleaner alternative to a coal-fired power plant. Both projects thus aimed to provide more stable, cleaner, and more efficient energy to these areas, and to avert any health risks related to local air pollution.

[3] In 2007, the populations of Jiujiang and Changsha were 4.69 million and 6.28 million, respectively.

electricity stabilization and improved air quality. It is clear that CR performance depends on respondents interpreting the questionnaire precisely, and that CR involves a larger burden on respondents compared with a CE. Therefore, we employed face-to-face interviews in Jiujiang and Changsha. Before implementation, we conducted preliminary face-to-face interviews with 30 samples at Tsinghua University in Beijing to improve the design of the CR questions and other parts of the questionnaire.

When designing the CR choice sets, we omitted opt-out options, even though options such as "no choice" are frequently included in many other studies. Including an opt-out option makes it possible to mimic the real-world situation (Ryan and Skåtun 2004), while including various types of no-opinion options reduces the sample size of yes and no responses (Fenichel et al. 2009). De Blaeij et al. (2007) used a nested logit model to demonstrate that including a no-preference option is relevant for the analysis. Conversely, Carlsson et al. (2007) used RPL, as a more flexible method than a nested logit model, to investigate the effect of including a not-to-buy option in the context of the purchase of minced beef. They suggested that there are no such effects on the marginal WTP. Therefore, we decided to omit these options, as well as the status quo option, from the choice sets in order to obtain a large sample size, and to concentrate on the residential preferences for a stable electricity supply and a reduction in health risk with only a marginal change in the utility.[4]

As an alternative to including a status quo option in the questionnaire, we described in detail the current levels of health risk at the time of the surveys, and advised respondents that power plants have a harmful effect on air quality. In calculating the levels, we decided to employ 0.800 as the average exposure concentration ratio (Iwai and Uchiyama 2000), and $3.000\times10^{-4}(\mu g/m^3)^{-1}$ as

[4] Indeed, similar studies have frequently omitted a status quo option because of the difficulty in setting such an option. For example, Carlsson and Martinsson (2008) omitted a status quo option because "…both the historical levels of outages as well as future levels vary a lot, and in most cases are related to random events, it is difficult to include a realistic status-quo alternative in a postal questionnaire" (Carlsson and Martinsson 2008, p. 1236).

the unit risk of PM_{10} (California Environmental Protection Agency 1998) because we could not find any adequate epidemiological studies or dose–response functions on air pollution and health risks in China.[5] According to the State Environmental Protection Agency (2006), the annual average PM_{10} concentration in 2006 was 92 $\mu g/m^3$ in Jiujiang and 122 $\mu g/m^3$ in Changsha. Therefore, we employed the number of cancer-related deaths per 10,000 over a 70-year period caused by air pollution at $0.800 \times 3.000 \times 10^{-4} \times 92 = 220.8$ in Jiujiang, and $0.800 \times 3.000 \times 10^{-4} \times 122 = 292.2$ in Changsha (see Appendix A).[6] In addition, because the respondents in both cities frequently experience power breakdowns, we assumed that they could easily compare their status quo on the number and duration of power breakdowns with the levels provided in our choice sets.

When creating the CR choice sets, we selected the number and duration of power breakdowns as the attributes of the stability and cost of the electricity supply, and chose the number of deaths from cancer caused by air pollution per 10,000 people over a 70-year period as the health risk attribute (Table 2). We selected the levels of the attributes as follows. We designed reasonable levels for the number and duration of power breakdowns and the cost of the electricity supply to mimic

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[5] Other forms of local air pollution, such as NO_x or SO_x, remain outside the scope of the analysis. As we could not find any epidemiological data on their association with health risk, we decided in this study to concentrate on the mortality and cancer risk related to PM_{10}. Elsewhere, Ito and Thurston (1996) examined the association between cancer risk and PM_{10} concentration, and Lee et al. (2002) examined the link between cancer risk and SO_2 concentration.

[6] According to the World Development Indicators, life expectancy in China was about 72.835 years in 2008 (World Develop Indicator in World Bank website, URL: http://data.worldbank.org/data-catalog/world-development-indicators).

the actual situation.[7] In particular, we employed identical levels of the number and duration of power breakdowns for the two sites. We then created the levels for the numbers of deaths from cancer caused by air pollution in accordance with the level at the time we administered the surveys. We set the levels of the health risk attribute to provide respondents with a hypothetically possible improved situation.

<**Table 2** Attributes and levels in the choice set>

We eliminated any possible correlation in the attributes in the experimental design methodology, primarily by using the main effects of a fractional factorial design. We created 16 profiles, and randomly selected three of these to create our choice sets. We provided three alternatives for each of the main CR questions, representing six choices per respondent (see Appendix B).

3.2 Econometric method

To analyze the CE data, we employ a random utility model where we define the utility of the respondent choosing alternative i as:

$$U_i = V_i + \varepsilon_i = \beta x_i + \varepsilon_i, \quad (1)$$

where V_i denotes the observable component, ε_i is the unobservable error component, and x_i is the attribute vector of alternative i, which has a marginal utility row vector of β (Louviere et al. 2000).

[7] Although we could have defined the annual cost of the electricity supply, we chose to define it on a monthly basis because we expected that respondents at each site typically perceive the cost of electricity on a monthly, not annual, basis.

Previous studies have frequently employed an additively separated form for the observable component, which we also utilize.

McFadden (1978) showed that the choice probability of i among J alternatives becomes CL with random utility maximization given a Type I extreme value distribution for the error component, as follows:[8]

$$P_i = exp(V_i)/\sum_j exp(V_j) \quad (2)$$

Beggs et al. (1981)and Chapman and Staelin (1982) extended the CL to a model for ranked data. Their model assumes that the ranking results from $J-1$ utility comparisons. The highest ranking is then for the best alternative from among the *J* alternatives, the second-highest ranking to the best alternative from among the remaining *J-1* alternatives, and so on. The probability of ranking r is as follows:

$$P_r = \prod_{k=1}^{J-1}[exp(V_k)/\sum_{j=k}^{J} exp(V_j)] \quad (3)$$

Revelt and Train (1998) demonstrated that RPL with the use of repeat data to estimate the choice probability with preference heterogeneities could relax the assumptions of CL, namely, preference homogeneity and the independence of irrelevant alternatives. The choice probability of respondent $n\ (n = 1, \cdots, N)$ is given as follows within the parameter space Ω:

$$\pi_{ni} = \int \prod_t P_{nit}\, f(\beta|\Omega) d\beta, \quad (4)$$

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[8] Assuming a strictly increasing, continuous, and strictly quasi-concave utility function.

where $t\ (t = 1, \cdots, T)$ denotes the number of times the respondent answers, and P_{nit} is the form of CL. Equation 3 replaces P_{nit} when using RPL with ranked data. Previous studies have frequently employed the normal distribution for $f(\beta|\Omega)$ known as a mixing distribution, which we also utilize.

We estimate the implicit price (IP) using the marginal utility parameter estimate, β, where the subscripts bid and q, respectively, denote the price attribute and the remaining attributes:

$$IP_q = -\beta_q(\cdot)/\beta_{bid}. \tag{5}$$

$\beta_q(\cdot)$ can have some functional form when a cross term is incorporated for the population characteristics and attribute q. For simplicity in estimating the IP, we set β_{bid} as the fixed parameter (cf. Revelt and Train 1998).

We employ Limdep 9.0 + NLOGIT 4.0 (Econometric Software, Inc., NY, USA) when estimating RPL, with 1,000 Monte Carlo simulations of the mean and the variance matrix of the mean parameters to estimate confidence intervals (CI) for the IP (Krinsky and Robb 1986). We set alternative specific constants (ASCs) for the leftmost and middle option in the choice set to test for alternative positional effects, as pointed out by Chrzan (1994). When conducting statistical tests of BT, we employ the complete combinatorial (Poe et al. 2005) and set 10% as the significance level to avoid a Type II error (cf. Baskaran et al. 2010, p. 1019).[9] In searching for the best-fit model for RPL, we give high priority to the significance of standard deviation parameters in order to grasp the structure of the preference heterogeneities. We then employ several measures of goodness-of-fit, including McFadden's ρ, the Akaike Information Criterion (AIC) and some variants (AIC3 and

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[9] We could have employed the two one-sided convolutions test in Johnston and Duke (2008), but chose not to given the restrictions placed on the preference heterogeneities (see also Baskaran et al. 2010, p. 1020).

crAIC), and the Bayesian Information Criterion. Table 3 provides estimates for the attribute variables and the many covariates.

4 Results

Table 3 provides the estimated results obtained using this procedure. As shown, there are alternative positional effects for each site because every positive ASC is significant. Although there may be a limitation at both sites concerning the unbiased welfare estimates, we assume the ASCs effectively represent the positional effects while the estimates of the remaining parameters denote the unbiased marginal utilities.

For the Jiujiang results, we discern heterogeneous preferences concerning the number and duration of power breakdowns because the estimates of the standard deviation parameters are statistically significant. Most of the estimates of the mean parameters are also significant, with the exception of the duration of power breakdown. As the number of power breakdowns increases, the number of deaths from cancer caused by air pollution and the cost of electricity supply correspond to a less preferred option, which is consistent with sound intuition. The results for the duration of power breakdown indicate that Jiujiang residents are more sensitive to the number than to the duration of power breakdowns, such that the preference estimates are neutral. We obtain significant estimates only for the cross term between the experience of a bronchitis diagnosis and the number of deaths from cancer caused by air pollution. This suggests that respondents with a household member who had had bronchitis preferred options with far fewer deaths from cancer caused by air pollution. The estimate of the mean IP is -6.935 (95% CI: -3.310; -10.603) for the number of power breakdowns and -0.446 (95% CI: -0.365; -0.539) for the number of deaths from cancer caused by air pollution.

For the Changsha results, we also observe heterogeneous preferences concerning the duration of power breakdowns given the significant estimates of the standard deviation parameter. Once again, most of the estimates of the mean parameters are statistically significant. These results suggest that the longer the duration of power breakdowns, the more likely the number of deaths from cancer caused by air pollution and the cost of electricity supply correspond to a less preferred option, which is consistent with sound intuition. However, we find significant estimates only for the cross term between actual monthly expenditure on electricity (which is significantly greater than zero across respondents) and the number of power breakdowns. In contrast, the estimate of the mean parameter for the number of power breakdowns is insignificant. Thus, an increase in both actual monthly expenditure on electricity and the number of power breakdowns corresponds to a less preferred option. Our estimate for the mean IP is -6.483 (95% CI: -3.391; -9.835) for the number of power breakdowns, -5.947 (95% CI: -4.397; -7.499) for the duration of power breakdowns, and -0.589 (95% CI: -0.500; -0.691) for the number of deaths from cancer caused by air pollution.

<**Table 3** RPL results>

We now consider the transferability of the IP estimates between the sites using the results for the complete combinatorial in Table 4. As we obtained a significant result for the cross term between the experience of a bronchitis diagnosis and the number of deaths from cancer caused by air pollution, we adjusted the IP estimate for the number of deaths from cancer caused by air pollution in Jiujiang by using the experience of a bronchitis diagnosis in Changsha. We classify this as a benefit transfer function. Although we cannot demonstrate BT for the duration of power breakdowns because of the insignificant parameter estimate in Jiujiang, the result for the complete combinatorial indicates that we cannot reject at the 10% level the transferability of the IP given the number of power breakdowns. Conversely, we can reject the transferability of the IP with regard to the number of deaths from cancer caused by air pollution.

<**Table 4** Complete combinatorial>

5 Discussion

As shown in Table 3, we obtain original benefit estimates at both sites. Because we specify the number and duration of power breakdowns per year and the cost of electricity supply per month, we multiply the IP estimates by 12. Thus, the benefit estimate of reducing the number of power breakdowns is about $\mathrm{RMB83/(times{\times}year{\times}household)}$ $(\sim 6.935 \times 12)$ in Jiujiang and $\mathrm{RMB78/(times{\times}yearhousehold)}$ $(\sim 6.483 * 12)$ in Changsha. The benefit estimate of reducing the duration of power breakdowns is insignificant in Jiujiang given preference heterogeneity, and is $\mathrm{RMB71/(hours{\times}year{\times}household)}$ $(\sim 5.947{\times}12)$ in Changsha.

We also multiply by 12 the IP estimate of reducing the number of deaths from cancer caused by air pollution. In addition, we obtain the annualized value of statistical life (VSL) estimates from the IP because we specified the number of deaths per 10,000 over a 70-year period. For example, if we employ 0.05 as the discount rate, the annualized VSL estimate for cancer risk caused by air pollution among citizens over a 70-year period in 2008 (at the time of our survey) is $\mathrm{RMB50{,}844/year}$ $(\sim 0.446{\times}12{\times}(1-0.05)/(1-0.05^{70}){\times}10{,}000)$ for Jiujiang and $\mathrm{RMB67{,}146/year}(\sim 0.589{\times}12{\times}(1-0.05)/(1-0.05^{70}){\times}10{,}000)$ for Changsha, on a household basis. According to the World Development Indicators, the official exchange rate between the RMB and the USD is about 6.949. Thus, we convert our estimates to $\mathrm{USD353{,}315\ in\ 2008}$ in Jiujiang, and $\mathrm{USD466{,}598\ in\ 2008}$ in Changsha.

We compare our VSL estimates with Wang and Mullahy (2006), who estimated the VSL in Chongqing at 286,000 RMB (34,583US$) in 1998 individually [10] According to the World Development Indicators, the Chinese consumer price index was about 94.598 in 1998 and 112.516 in 2008. Thus, the price-adjusted VSL estimate from Wang and Mullahy (2006) is about 41,133US$ in 2008/year ($\sim 34{,}583 \times 112.516/94.598$) in individual terms. This suggests that our estimates for Jiujiang and Changsha are somewhat larger, even if we take into account the differences between the numbers of households and the population in the two studies.[11] We attribute the difference mainly to our CR design because we provided respondents with options that were closer to private purchase, even though our CR surveys and the estimation model also include methodological improvements over the open-ended CVM format in Wang and Mullahy (2006). In addition, we identify some heterogeneous preferences for stable electricity supply. A reduction in the duration of power breakdowns is heterogeneously preferred at both sites, while that concerning the number of power breakdowns is only in evidence in Jiujiang. This suggests that we should incorporate a heterogeneous preference structure for a stable electricity supply if we consider the CBA for a reliable electricity supply.

The results in Table 4 indicate that the benefit of reducing the number of power breakdowns is transferrable with the other site. This provides us with reliable BT results to incorporate preference heterogeneity, which is also consistent with the implications of previous studies. In addition, Jiujiang and Changsha have similar characteristics in terms of the population size, which suggests

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[10] Although we could compare our results with those in Hammitt and Zhou (2006), their results concerning fatality risk suffer from scope insensitivity concerning the magnitude of the risk reduction. We thus omit the comparison.

[11] According to the Statistical Bureau of Jiangxi Province (2007), Jiujiang had a population of around 4.69 million and about 1.46 million households in 2006. The Statistical Bureau of Hunan Province (2007) reported that in 2006 Changsha had a population of about 6.28 million and some 1.87 million households.

that the transferability is also attributable to site similarity. Conversely, the benefit of reducing the duration of power breakdowns is not transferable because the IP in Changsha is insignificant. Given that preferences for a reduction in the duration of power breakdowns differ between the sites, we should not transfer the benefit, even though the sites appear similar and we incorporate preference heterogeneity into the estimation. Furthermore, we reject transferability based on the benefit of reducing the number of deaths from cancer caused by air pollution, even if we incorporate the covariates for an experience of bronchitis diagnosis. This suggests that site similarity and/or adjustments for individual characteristics may not work sufficiently well to obtain a transferable benefit estimate for the reduction in the risk of air pollution in China. Therefore, we recommend that we conduct original studies to estimate the benefit from reducing the duration of power breakdowns and VSL estimates related to the reduction in the risk of air pollution in China.

6 Conclusion

In this paper, we conducted CR surveys and BT analysis of the preferences for a stable electricity supply and a reduction in the risk of air pollution in Jiujiang and Changsha, China. In terms of the original benefit estimates, the benefit of reducing the number of power breakdowns is about $83\ \mathrm{RMB}/(\mathrm{time}\times\mathrm{year}\times\mathrm{household}$ in Jiujiang and $78\mathrm{RMB}/(\mathrm{time}\times\mathrm{year}\times\mathrm{household})$ in Changsha. However, the benefit of reducing the duration of power breakdowns is statistically zero in Jiujiang and $71\ \mathrm{RMB}/(\mathrm{hour}\times\mathrm{year}\times\mathrm{household})$ in Changsha. Household estimates of the annualized VSL estimate of the risk of cancer caused by air pollution for residents over a 70-year period is $\mathrm{RMB}50{,}844\ \mathrm{in}\ 2008$ in Jiujiang and $\mathrm{RMB}67{,}146\ \mathrm{in}\ 2008$ in Changsha. Preference heterogeneity exists in relation to the reduction in the duration of power breakdowns at both sites, and we observe a reduction in the number of power breakdowns only in Jiujiang. The results also suggest that we cannot statistically reject IP transferability for the number of power breakdowns, partly because the model incorporates preference heterogeneity into the estimation and partly because of the similarities between the two sites.

Conversely, we can reject the duration of power breakdowns and the number of deaths from cancer caused by air pollution, even though we incorporate preference heterogeneity for the former or adjust the benefit estimate with the covariate at the policy site for the latter. This suggests that we are able to transfer the benefit of the reduction in the number of power breakdowns, and that we should conduct original surveys concerning the benefits of the duration of power breakdowns and the reduction in the risk of air pollution. Unfortunately, we were unable to identify the source of the heterogeneity in preferences that emerged in the analysis. This suggests that further research should attempt to analyze how the attitudinal covariates influence the sources of heterogeneity in preferences on power outages and the reduction in the air pollution risk. Latent class approaches (see Greene and Hensher 2003 for further details) are just one of several ways to address this outstanding issue.

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Tables

Table 1 Demographic statistics

Item	Subitem		Jiujiang	Changsha
Gender	Male	No.	108	126
	Female	No.	117	71
Age		Mean	37.489	31.821
		S.D.	13.596	11.404
Number of household members		Mean	4.013	3.597
		S.D.	1.495	1.006
Annual household income (RMB/year)		Mean	30,035.874	53,319.608
		S.D.	25,947.514	31,154.073
Actual monthly electricity expenditure (RMB/month)		Mean	118.460	130.208
		S.D.	92.933	88.431
Actual monthly electricity usage (voltage/month)		Mean	172.014	157.566
		S.D.	133.572	127.299
Perceived number of power breakdowns in 2007 (times/month)		Mean	8.222	11.270
		S.D.	13.563	21.761
Perceived duration of power breakdowns in 2007 (hours/month)		Mean	10.282	8.843
		S.D.	23.015	21.042
Diagnosis of household member	Asthma	No.	10	35

(Number of responses: Multiple responses)	Heart disease	No.	12	31
	Respiratory disease	No.	17	54
	Bronchitis	No.	26	41
	Chronic cough	No.	10	44
	High blood pressure	No.	30	59
	Cancer	No.	0	29
	None	No.	155	95

Table 2 Attributes and levels in the choice set

	Jiujiang	Changsha
Number of power breakdowns (times/year)	(1, 2, 3, 4)	
Duration of power breakdowns (hours/year)	(1, 3, 5, 7)	
Number of deaths from cancer caused by air pollution (per 10,000 residents over a 70-year period)	(40, 100, 160, 220)	(150, 200, 250, 300)
Cost of electricity supply (RMB/month)	(55, 75, 95, 115)	(50, 70, 90, 110)

Table 3 Estimated results with CR data

	Site	Jiujiang		Changsha	
	Variable in utility function	Coef.	IP estimate	Coef.	IP estimate
Mean	ASC of left alternative	0.383***		0.252***	
		(6.390)		(4.053)	
	ASC of middle alternative	0.498***		0.178**	
		(8.708)		(2.873)	
	No. of power breakdowns	−0.108***	−6.935	−0.012	−6.483
		(−3.718)	[−3.310; −10.603]	(−0.301)	[−3.391; −9.835]
	No. of power breakdown × actual monthly electricity expenditure			−0.001***	
				(−3.938)	
	Duration of power breakdowns	−8.347E−03		−0.120***	−5.947
		(−0.491)		(−5.999)	[−4.397; −7.499]

	Number of deaths from cancer caused by air pollution	−6.069E−03***	−0.446	−0.012***	−0.589
		(−13.142)	[−0.365; −0.539]	(−17.159)	[−0.500; −0.691]
	Number of deaths from cancer caused by air pollution × bronchitis diagnosis	−7.192E−03***			
		(−4.519)			
	Cost of electricity supply	−1.556E−02***		−0.020***	
		(−10.207)		(−11.924)	
S.D.	No. of power breakdowns	0.404***			
		(11.542)			
	Duration of power breakdowns	0.150***		0.224***	
		(8.271)		(13.436)	
	No. of samples	225		197	
	No. of observations	1,348		1,180	

Log likelihood	−2,193.227	−1,855.530
Halton replications	100	100
McFadden's ρ (constant only)	0.077	0.120

Note: *** and ** indicate significance at the 0.1% and 1% level, respectively; t-values in parentheses. 95% confidence interval of the IP in brackets. We used the characteristics of each site when calculating the IP for the number of deaths from cancer caused by air pollution in Jiujiang and the duration of power breakdowns in Changsha.

Table 4 Complete combinatorial

	$IP_{\text{Policy Site}}$	$IP_{\text{Study Site}}$	Complete combinatorial
No. of power breakdowns	−6.483	−6.935	*0.573*
	[−3.391; −9.835]	[−3.310; −10.603]	
Number of deaths from cancer caused by air pollution	−0.589	−0.491	0.080
	[−0.500; −0.691]	[−0.399; −0.595]	

Note: $IP_{\text{Policy Site}}$ is the IP estimate for Changsha, and $IP_{\text{Study Site}}$ is the estimate using the marginal utility parameter estimate for Jiujiang with adjustment for the population characteristics of Changsha as necessary. Figures in italics indicate that the IPs are transferable at the 10% level. The result for the duration of power breakdowns is omitted because the IP is not significant at the study site (see also Table 3).

Appendix A Description of the status quo in the questionnaire

Suppose you select the location of your residence by considering the electricity conditions in each location.

This questionnaire provides three alternative scenarios: Plan 1, Plan 2, and Plan 3. Each plan offers a different combination of the number of power breakdowns (frequency, times/year), duration of power breakdowns (the aggregate duration of power breakdowns, including regular maintenance, minutes/year), the number of deaths from cancer caused by air pollution (number of people per 10,000 citizens over a 70-year period who die from cancer caused by air pollution), and the cost of electricity supply (RMB/month).

Currently air pollution is severe in Jiujiang/Changsha, and causes cancer deaths at a rate of ____ (220.8 for Jiujiang and 292.2 for Changsha) people per 10,000 citizens over a 70-year period. This means that, out of 1,000 people who live in Jiujiang/Changsha for 70 years, about ____ (22 for Jiujiang and 29 for Changsha) will die from cancer caused by air pollution. Power stations also have a harmful influence on air quality.

Appendix B Example of a choice set

＜example＞

	Plan 1	Plan 2	Plan 3
Number of power breakdowns (times/year)	4	3	1
Duration of power breakdowns (hours/year)	5	3	1
Number of deaths from cancer caused by air pollution (deaths per 10,000 people over a 70-year period)	40	40	220
Cost of electricity supply (RMB/month)	55	75	95
Rank the plans according to their desirability	3	2	1

This example shows that Plan 3 is the most desirable plan.

This example shows that Plan 1 is the least desirable plan.