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A Lifeline for U.S. Nuclear?

C.K. Woo *is an economics professor at the Hong Kong Baptist University. He is a senior fellow of the U.S. Association of Energy Economics and an editorial board member of* Energy *and* The Energy Journal. *He holds a Ph.D. in Economics from the University of California – Davis.*

Alice Shiu *is an assistant professor at the School of Accounting and Finance, Hong Kong Polytechnic University. She holds a Ph.D. in Economics from the University of New South Wales.*

Y.S. Cheng *is an associate professor in the Economics Department of Hong Kong Baptist University. He holds a Ph.D. in Economics from Adelaide University.*

Ray Li *is a teaching fellow at the School of Accounting and Finance, Hong Kong Polytechnic University. He holds a Ph.D. in Economics from Macquarie University.*

Tony Ho *is a senior research assistant at the Economics Department of Hong Kong Baptist University. He holds an M.Phil. in Statistics from the Chinese University of Hong Kong.*

Ira Horowitz *is a graduate research professor emeritus at the University of Florida. He was Editor-in-Chief of Decision Sciences and Managerial and Decision Economics. He holds a Ph.D. in Economics from MIT.*

Jianhui Wang *is a computational engineer at the Argonne National Laboratory. He is an editor of the IEEE Transactions on Power Systems and the IEEE Transactions on Smart Grid. He holds a Ph.D. in Electrical Engineering from the Illinois Institute of Technology.*
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Residential Willingness-to-Pay for Reducing Coal-Fired Generation's Emissions in Hong Kong

Hong Kong residents' willingness-to-pay estimate for a 30 percent emissions reduction via natural-gas-fired generation is an 18 percent annual electricity bill increase, twice the estimate for nuclear power. Since these WTP estimates are below the projected bill increase required to achieve the government's emissions reduction target, they suggest that a narrow supply-side focus on the generation fuel mix may not be publicly acceptable. The solution is a more comprehensive policy that would include energy efficiency investment and vehicular emissions reductions.

C.K. Woo, Alice Shiu, Y.S. Cheng, Ray Li, Tony Ho, Ira Horowitz and Jianhui Wang

I. Introduction

On July 1, 1997, Hong Kong became the Hong Kong Special Administrative Region (HKSAR) of China under the framework of ''one country, two systems.'' Over the past 17 years, it has achieved a remarkable economic performance, one that is aided by its superbly reliable electricity supply. Its 7.2 million residents' per capita GDP in 2012 was US$36,590 and its unemployment rate in 2013 was 3.3 percent, which rivals the performance of OECD countries.[1] Accompanying this performance, however, has

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Table 1: Hong Kong's Local Emissions (Kilo-tons/Year) by Source Based on Environmental Protection Department (2011, 2013); All Emissions Data are 2011 Values Except for Carbon Dioxide (CO_2), Which are 2010 Values.

Emissions Type	Electricity Generation	Transportation	Other	Total
Sulfur dioxide (SO_2)	14.00	17.41	0.54	31.95
	(44%)	(55%)	(1%)	(100%)
Nitrogen oxides (NO_x)	30.00	70.40	14.06	114.46
	(26%)	(62%)	(12%)	(100%)
Respirable suspended particulates (RSP or PM_{10})	1.00	3.49	1.74	6.23
	(16%)	(56%)	(28%)	(100%)
Volatile organic compounds (VOC)	0.45	11.35	21.11	32.90
	(1%)	(35%)	(64%)	(100%)
Carbon monoxide (CO)	3.72	57.90	6.95	68.57
	(5%)	(85%)	(10%)	(100%)
Carbon dioxide (CO_2)	27,400	7,390	6,710	41,500
	(66.0%)	(17.8%)	(16.19%)	(100%)

been a deterioration in air quality. Table 1 shows that along with transportation, electricity generation is a major source of local emissions. And as shown in Table 2, Hong Kong's generation mix is dominated by coal, as in China, India, Europe, the U.S., Australia and other parts of the world.[2]

In support of global efforts to mitigate climate change, China's Central Government announced in November 2009 a voluntary 2020 target of reducing China's ratio of CO_2 emissions to GDP by 40–45 percent of the 2005 level, under the Copenhagen Accord drafted by the United States, China, India, Brazil, and South Africa during the 2009 United Nations Climate Change Conference. In 2010, China reaffirmed the proposed target (Department of Climate Change, 2010). In concert, the HKSAR Government proposed an even more aggressive target of a 50–60 percent reduction in carbon intensity, implying an absolute

Table 2: Local System Characteristics of Hong Kong Electric (HKE) and China Light and Power (CLP) in 2012.

Variable	HKE	CLP
Number of customers (000)	567	2,400
System sales (000 MWH)	11,036	31,995
System peak (MW)	2,494	6,769
System capacity (MW)	3,737	8,888
Reserve margin = system capacity as percent of system peak (%)	49.8	31.3
Generation mix (MW)		
Coal	2,500	4,108
Natural gas	680	2,500
Nuclear	0	1,378
Other	557	902
System average of unplanned outage minutes per customer	Under 5	2.6
System average interruption duration index (SAIDI) = minutes per customer = total customer interruption minutes/Total number of customers	Not available	30

Sources: 2012 Annual Reports issued in 2013 by HKE (Power Assets Holdings Ltd., 2012) and CLP (China Light Power, 2013a,b) and communication on 6 May 2013 with C.W. Tso, a former General Manager (Projects) of HKE.

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reduction of 19–33 percent in total greenhouse gas (GHG) emissions, from 42 million tons in 2005 to 28–34 million tons in 2020 (Environmental Protection Department, 2013; Environment Bureau, 2010). It also announced that the target was to be achieved by a drastic change in the territory's generation fuel mix (Environment Bureau, 2010).

If implemented, the proposed changes in the fuel mix would alter Hong Kong's mix from 54 percent coal, 23 percent natural gas, and 23 percent imported nuclear power in 2009, to less than 10 percent coal, 40 percent natural gas, 3–4 percent renewable energy, and 50 percent imported nuclear power in 2020. The government justifies the large increase in nuclear power imports from Southern China as a relatively inexpensive means of displacing local coal-fired generation. It also justifies the increased use of natural gas based on its low cost relative to that of renewable energy and its relatively low emissions when compared to coal. Renewable energy is unlikely to play a major role due to severe land limitations, cost concerns, and public acceptance.[3]

Shortly after the government's three-month public consultation on its emissions reduction proposal, the Tohuku earthquake and its ensuing tsunami hit Japan on March 9, 2011, precipitating the Fukushima nuclear disaster. The immediate response of China's Central Government was a comprehensive safety inspection of all its nuclear plants, and suspension of approval for new nuclear power stations. This response echoes Germany's decision to immediately shut down eight of its 17 reactors and to close the rest by 2022, and Italy's widely supported referendum in 2011 to reject nuclear power. Two years after the Fukushima disaster, Japan has yet to contain its long-lasting damages: heavily contaminated water continues leaking at the nuclear plant into the soil and sea (Kubota and Obayashi, 2013; Hirokawa et al., 2013).

Shortly after the government's three-month public consultation on its emissions reduction proposal, the Tohuku earthquake and its ensuing tsunami hit Japan.

Fukushima has sharply altered the public perception of nuclear-power safety in Hong Kong, resulting in calls to revise the government's proposed change in the fuel mix (Cheung, 2012). Without nuclear power imports, however, local natural-gas-fired generation becomes the only practical, though more costly, supply-side alternative to meet the government's target. The question thus arises as to the amount that Hong Kong residents are willing to pay for reducing the emissions from coal-fired generation. If their willingness-to-pay (WTP) is substantially less than the increases in their electricity bills triggered by the government's fuel-mix proposal, the proposal would have to be revised to gain public support, thus altering Hong Kong's electricity future.

We address the WTP question by statistically analyzing the responses of 1,876 households to a telephone survey conducted in June 2013. Our estimates contribute to Hong Kong's ongoing emissions reduction debate (Hong Kong SAR Government, 2013). Specifically:

- If the WTP estimate is large, a high target could be set without strong public objection. If, however, the WTP estimate is small, public support for the high target may require financial mitigation of the ensuing bill increase, possibly with taxpayer money or utility shareholders' earnings.
- The Fukushima disaster and its aftermath suggest that the WTP estimate for nuclear power could be substantially less than the WTP estimate for natural-gas-fired generation. As a result, a publicly acceptable fuel mix would contain less nuclear power.

Our key findings are as follows:

- The residential WTP estimate for a 30 percent emissions reduction by the electricity sector through natural-gas-fired generation is an 18 percent annual bill increase, or about HK$1,834 = US$235 per year at the pegged exchange rate of HK$7.8 = US$1. The upper bound

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of the 95 percent confidence interval for this WTP estimate is a 27 percent annual bill increase, or about HK$2,890 = US$370 per year.

- The residential WTP estimate for the same 30 percent emissions reduction achieved through nuclear generation is half that achieved through natural-gas-fired generation. Thus, residents are willing to pay HK$990 = US$127 per year to avoid nuclear generation.

Taken together, these findings indicate a lack of compelling empirical evidence of Hong Kong residents' support for (1) China Light and Power's projected 40 percent rate increase required to achieve the government's emissions reduction target (China Light Power, 2012); and (2) China Light and Power's proposal to increase nuclear power imports (China Light Power, 2010). These findings do, however, support the calls to revise the government's proposal for reducing emissions from coal-fired generation, which is now taking shape through expanded funding for energy efficiency,[4] and actions to reduce vehicular emissions.[5]

II. Data Collection

We collected our data in a June 2013 telephone survey of 1,876 randomly chosen households.[6] Following the contingent valuation method (CVM) (Bateman and Willis, 2001; Champ et al., 2003; Mitchell and Carson, 1989),[7] our questionnaire has four parts.[8] Part I is a self-introduction by the interviewer to explain the purpose of the survey and to assure confidentiality of the respondents' information. Part II aims to identify the appropriate respondent: the person who is familiar with the household's electricity bill. Part III has two sections that form our choice experiment. Part IV collects the demographic data that will enable us to determine whether residential WTP estimates systematically vary with household attributes.

The findings support the calls to revise the government's proposal for reducing emissions from coal-fired generation.

Section A of Part III helps respondents recall their electricity rates. It also aids their awareness of the emissions from electricity generation, thus mitigating the potential hypothetical bias (Bateman and Willis, 2001, p. 200) that may arise in a choice experiment.

To further mitigate the potential hypothetical bias, Section B first informs the respondent of (1) the current share of local emissions from electricity generation, and (2) the relationship between emissions and bill levels when using nuclear power or natural gas to displace coal in electricity generation. It then elicits household preferences for the bill and emissions levels after fuel switching has occurred. A respondent may answer ''yes,'' or ''not sure,'' or ''no'' to a choice question regarding a particular combination of bill and emissions.

To detect any status quo bias in consumer behavior (Hartman et al., 1991; Samuelson and Zeckhauser, 1988), the first question is: ''Changing emissions level from electricity generation can affect your electricity bill. Would you accept this change?'' If there is a strong sentiment against the status quo, most respondents are likely to answer ''yes.''

The two WTP questions that produce the requisite response data are as follows:

- ''Would you pay an average monthly bill increase of m% for increasing share of natural gas in current fuel mix to reduce n% of emissions from electricity generation?''
- ''Would you pay an average monthly bill increase of m% for increasing share of nuclear in current fuel mix to reduce n% of emissions from electricity generation?''

There are nine versions of these WTP questions, each formed by a combination of m = 5%, 15% or 25% and n = 10%, 20%, or 40%. These m and n values are so chosen to span the plausible outcomes perceived by Hong Kong residents from implementing the government's emissions reduction policy.

Table 3: Descriptive Statistics of 1,876 Survey Respondents.

Variable	Mean	Standard Deviation	Maximum	Minimum
Age of respondent	50.93	13.41	70	22
Family size	3.22	0.93	4	1
Years of education	12.36	3.39	16	6
Monthly income (HK$)	18,528	17,659	80,000	7,500
Number of children	0.49	0.80	3	0
Years of living in Hong Kong	21.81	2.69	22.5	0.5
Monthly electricity bill (HK$)	833	623	6,000	20

Table 3 shows the heterogeneous demographics of the respondents to the survey, presaging the diversity in the residential WTP estimates.

Fig. 1 reports the relative frequencies of responses to the status quo and the WTP questions for natural-gas-fired generation. Over 70 percent of the respondents support a change from the status quo. For case 1 of a 40 percent emissions reduction, 72 percent of the respondents said ''yes'' to a 5 percent bill increase. When the bill increase is 15 percent (25 percent), only 64 percent (43 percent) supported the 40 percent emissions reduction target. The other two cases portray a similar response pattern.

Fig. 2 reports the relative frequencies of responses to the status quo and the WTP questions for nuclear generation. When compared to Fig. 1, the share of ''yes'' responses is under 50 percent for all three emissions reduction targets, indicating the relative unpopularity of nuclear generation among the general public.

Finally, a comparison of Figs. 1 and 2 suggests more support for natural-gas-fired generation than for nuclear generation, implying that the WTP estimate for natural-gas-fired generation is higher than that for nuclear generation. Since both generation technologies are seen by respondents to achieve the same reduction in emissions, the difference between the two fuel-specific WTP estimates quantifies a respondent's WTP to avoid nuclear generation.

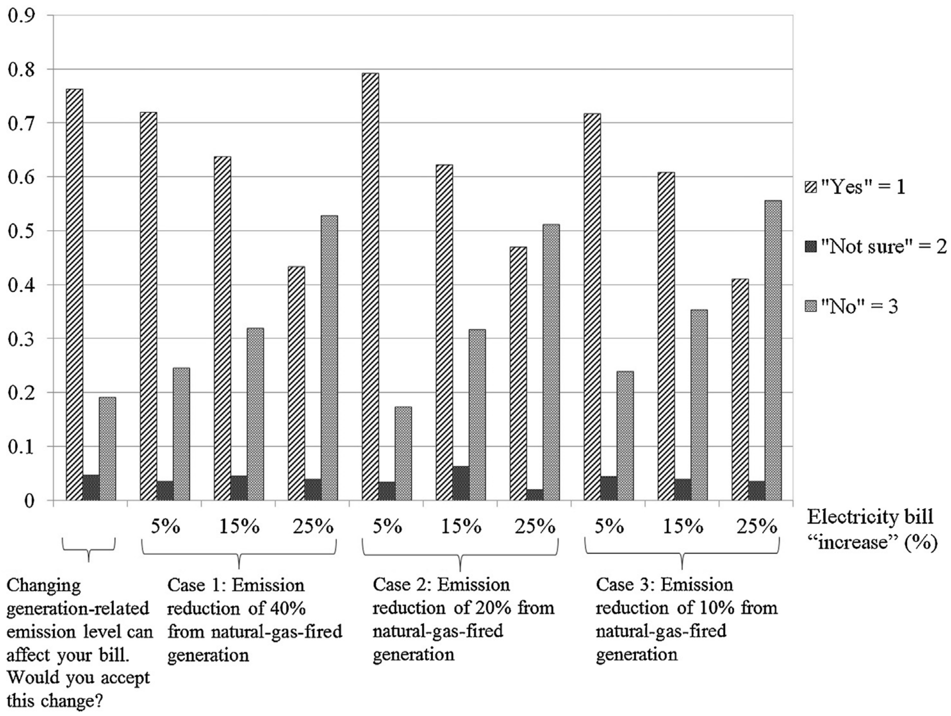

Figure 1: Relative Frequencies of Response to the Status Quo and WTP Questions for Reducing Coal-Fired Generation's Emissions Via Natural-Gas-Fired Generation

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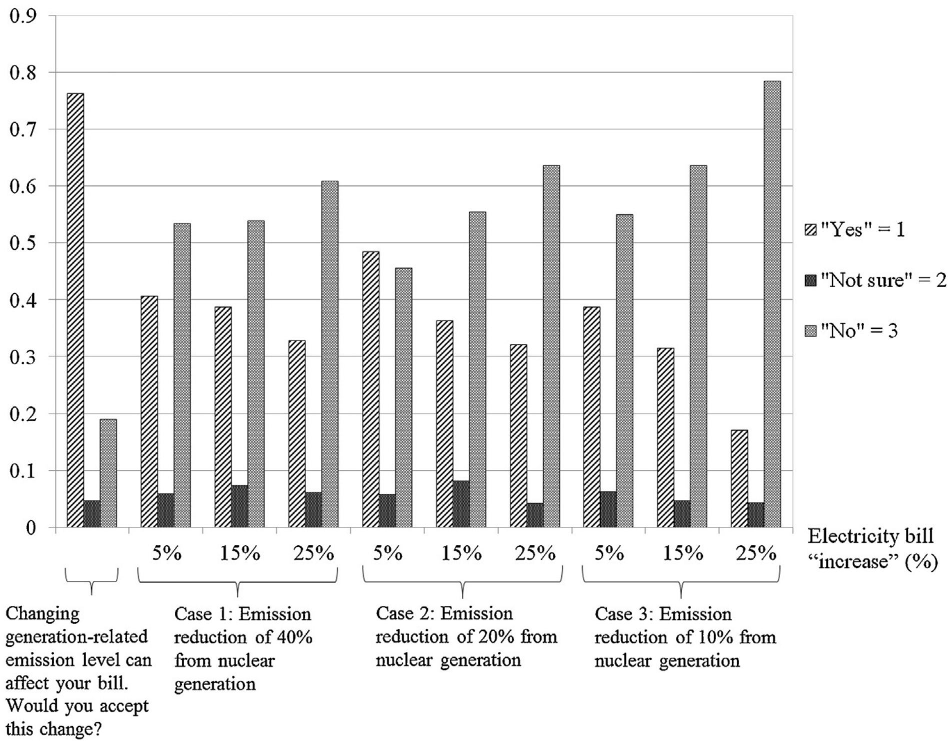

Figure 2: Relative Frequencies of Response to the Status Quo and WTP Questions for Reducing Coal-Fired Generation's Emissions Via Nuclear Generation

III. WTP Estimates

Appendix B details our statistical approach for WTP estimation. Fig. 3 reports the WTP estimates thus obtained by fuel type and their confidence intervals in percent of bill increase. The two cases of particular interest are as follows:

- Case 1: A 30 percent emissions reduction, which is close to the top (33 percent) of the target range set by the government for Hong Kong's total GHG reduction. It corresponds to the assumption that the electricity sector would reduce emissions at roughly the same proportion as other sectors. For this case, the natural-gas WTP estimate is about 18 percent and has an upper bound of about 27 percent.

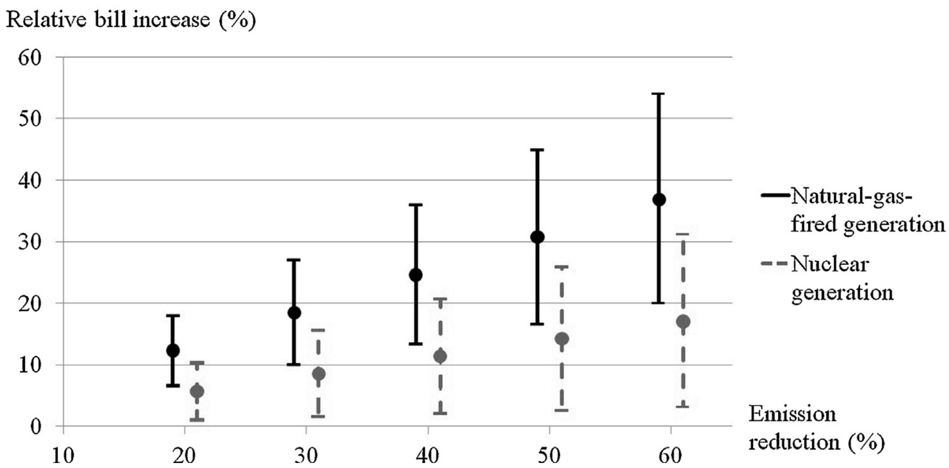

Figure 3: WTP Estimates (Solid Dots) in Percent of Bill Increase and Their 95% Confidence Intervals by Emissions Reduction and Fuel Type

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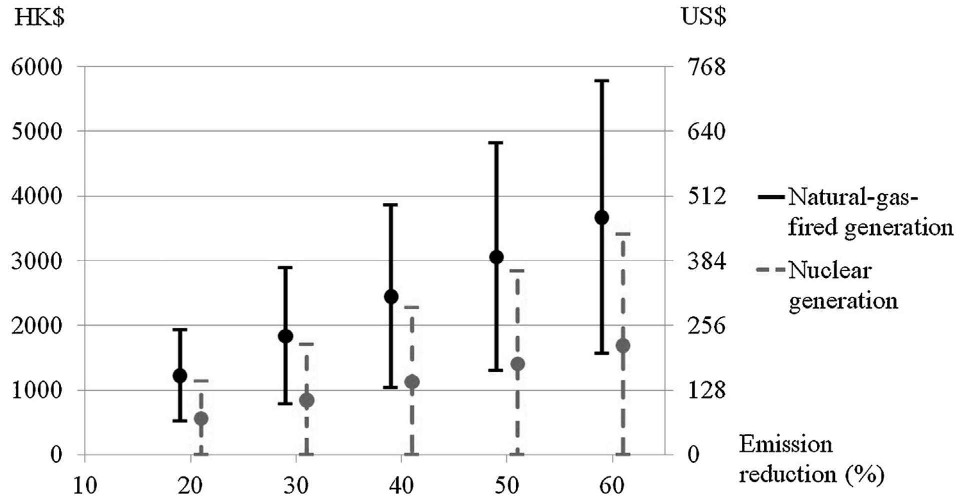

Figure 4: WTP Estimates (Solid Dots) in Dollar Bill Increase and Their 95% Confidence Intervals (US$1 = HK$7.8) by Emissions Reduction and Fuel Type

- Case 2: A 50 percent emissions reduction, which corresponds to the assumption that the total emissions reduction for Hong Kong would solely come from the electricity sector. For this case, the natural-gas WTP estimate is about 31 percent and has an upper bound of about 45 percent.

For both cases, the natural-gas WTP estimate is about twice the nuclear power WTP estimate.

Fig. 4 reports our residential WTP estimates in dollars of bill increase by fuel type and their confidence intervals in annual dollar bill increase. For the 30 percent emissions reduction case, the natural-gas WTP estimate is HK$1,834 = US$235 per year and has an upper bound of about HK$2,890 = US$370 per year. These estimates are at the high end of the range of WTP estimates reported in Appendix A. For the 50 percent emissions reduction case, the nature-gas estimate is HK$3,057 = US$392 and its upper bound is HK$4,816 = US$617. These natural-gas WTP estimates are about twice the nuclear power WTP estimates.

IV. Conclusion

Based on a report from the University of Hong Kong, an article appearing in the *Hong Kong Standard* on Jan. 18, 2012, stated that there are an estimated 3,200 annual deaths in the territory from pollution and an annual economic loss of HK$40 billion.[9] The environmental concerns of the citizenry are real and have a sound basis. But are they willing to open their pocketbooks to relieve those concerns?

We document that Hong Kong residents are indeed willing to pay higher electricity rates for using natural-gas-fired generation to displace coal-fired generation. While our residential WTP estimates are at the high end of the range of estimates in 16 studies mostly published in the last five years, they are likely below the projected bill increases required to achieve the government's targeted emissions reduction. Moreover, the natural-gas WTP estimates are found to be twice the nuclear power WTP estimates. These findings suggest that a narrow supply-side focus on the generation fuel mix may not be publicly acceptable. Hence, steps have been taken to (1) increase funding in support of energy efficiency,[10] and (2) reduce vehicular emissions.[11] These steps affirm the government's belief that a comprehensive emissions reduction policy should include investment in energy efficiency to reduce usage, as well as the adoption of clean fuel improvements in fuel efficiency that would reduce emissions from the transportation sector.

Appendix A. Literature Review

This appendix reviews the extant approaches for quantifying household valuation of reduced emissions. Table A1 summarizes

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Table A1: Recent Estimated Willingness-To-Pay (WTP).

Study	Country	Resource Type	Data Collection/ Estimation Method	Reported Estimate (Data Year)	Households' WTP Per Year	WTP Estimates in 2012 US$
Jun et al. (2010, p. 1475)	South Korea	Nuclear power	CVM: choice experiment/MLE approach	6.575 US$/capita-year (2007)	19.07 US$	21.12
Liao et al. (2010, p. 7062)	Taiwan	Nuclear power	Modified double-bounded CVM/ random parameter technology	4,828.39 NT$ (146.31 US$)/ adult-year (2009)	9,656.78 NT$ (292.62 US$)	313.16
Chou et al., 2011, p. 17)	France, Italy & UK	Natural gas	CVM: choice experiment/MLE approach	2.65 €/cubic meter in UK (2010)	1,113.67 €	1,811.80
Damigos et al., (2009, Table 7)	Greece	Natural gas	CVM: self-stated/ non-parametric estimation	7.6–9.7 €/household-month (2007)	91.2–116.4 €	132.88–169.59
Goto and Ariu (2010, p. 3)	Japan	Nuclear/renewable energy (solar)	CVM: self-stated/ tobit model	0.4 yen/kWh 1.6 yen/kWh (2009)	2,205.2 yen 8,820.8 yen	25.19 100.76
Grösche and Schröder (2011, Table 4)	Germany	Nuclear/unspecified renewable energy	CVM: Hedonic approach/random parameter technology	20.33 ct/kWh; 22.7 ct/kWh (2008)	713.99 US$ 797.22 US$	761.38 850.14
Roe et al. (2001, Table 2)	US	Nuclear/renewable energy (hydro, solar, and wind)	CVM: Conjoint analysis/OLS	5.50–14.88 US$ 1.48–9.99 US$/ capita-year (1998)	16.32 US$ (2005)	19.19
Borchers et al. (2007, Table 4)	US	Renewable energy (wind, solar, farm methane, and biomass)	CVM: choice experiment/choice probability	14.77 US$/household-month in a 10% voluntary green energy programs (2000)	177.24 US$	236.31
Longo et al. (2008, Table 9)	UK	Unspecified renewable energy	CVM: choice experiment/ conditional logit	29.65 US$/household × year (2005)	29.65 US$	34.86
Menges and Traub (2009, p. 350)	Germany	Unspecified renewable energy	Experimental study/ ANCOVA approach		56 €	82.29

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Table A1: (*Continued*)

Study	Country	Resource Type	Data Collection/ Estimation Method	Reported Estimate (Data Year)	Households' WTP Per Year	WTP Estimates in 2012 US$
				56 €/(household-year) under the benchmark category (2005)		
Nomura and Akai (2004, p. 461)	Japan	Renewable energy (photovoltaic and wind energy)	CVM: choice experiment/MLE approach	2,000 yen (17.39 US$)/household-month (2000)	24,000 yen (208.70 US$)	278.26
Oliver et al. (2011, Table 4)	South Africa's Cape Peninsula	Unspecified renewable energy	CVM: self-stated/ multiple logistic regression model	R101.31/household-month (2006)	R1,215.72	193.83
Yoo and Kwak (2009, p. 5414)	South Korea	Unspecified renewable energy	CVM: choice experiment/ non-parametric methods	KRW2,072 (2.2 US$)/ household-month (2006)	KRW24,864 (26.4 US$)	30.07
Carlsson and Johansson-Stenman (2000, Table 2)	Sweden	Emissions (air pollution) reduction with unspecified resource	CVM: self-stated/tobit model	SEK2,000/capita-year for a 50% reduction of harmful substances (1996)	SEK3,980	868.19
Carlsson et al. (2012, Table 4)	China, Sweden & US	Emissions (CO_2) reduction with unspecified resource	CVM: choice experiment/tobit model	4.99 US$ in China US$ in Sweden 17.27 US$ in US/ (household-month) for 30% reductions in emissions (2009)	59.88 US$ US$ 207.24 US$	64.08 278.68 221.78
Kotchen et al. (2013, p. 12)	US	Emissions (greenhouse gas) reduction with unspecified resource	CVM: self-stated/ choice probability	79–89 US$/household-year for domestic reductions in greenhouse gas emissions by 17% by 2020 (2010–2011)	79–89 US$	80.63–90.84

Note: The last column's estimate are found by (1) adjusting the original estimate with the average exchange rates in corresponding year; and (2) converting the results for inflation (measured by CPI) in US$. The exchange rate and CPI figures are from economic statistics published by the U.S. Bureau of Labor Statistics in July 2013.

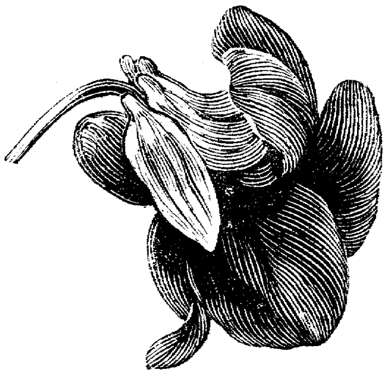
the estimates from a selected sample of 16 recent publications, a majority of which emphasize nuclear power, natural-gas-fired generation and renewable energy.

A.1. Approaches

Electricity generation imposes environmental costs on households. Such costs can be measured by: (1) direct cost (DC), which is the sum of out-of-pocket (e.g. health-care costs associated with air-pollution illness) and other costs (e.g. smoggy sky and productivity loss); (2) willingness-to-accept (WTA), which is the amount that one is willing to accept to tolerate emissions from generating electricity; and (3) willingness-to-pay (WTP), which is the amount that one is willing to pay to avoid those emissions.

A comprehensive survey of these studies is well beyond the scope of this article. Thus, we focus on studies of emissions reduction via fuel switching and renewable resources. Since our analysis is based on survey data, we pay particular attention to studies that use the contingent valuation method (CVM), a common technique for quantifying household valuation of environmental goods (Bateman and Willis, 2001; Champ et al., 2003; Mitchell and Carson, 1989).

There are two ways to obtain residential CVM survey data. The first is to ask survey respondents to directly self-state their WTA to tolerate, DC caused by, and WTP to avoid, emissions in electric power generation. The presence of many zero-value observations renders ordinary least squares (OLS) inappropriate for estimating an emissions-cost regression, and makes the Tobit estimation procedure more appropriate (Maddala, 1983). The second way is to collect customer



preference data to infer the tradeoffs that households are willing to make between electricity bills and emissions. For an emissions reduction, the bill change required to keep a household as well off as before the reduction is the requisite WTP estimate. That estimate is the metric we use to gauge public support for the HKSAR Government's proposed emissions reduction target.

There are two ways to collect customer preference data:

- A choice experiment that asks survey respondents to make a discrete choice from a menu of mutually exclusive emissions-differentiated options, each of which depicts a bill level (e.g. high) commensurate with an emissions level (i.e. low). To analyze these customer responses, one can use a logit regression model (Train, 2009; Greene and Hensher, 2010).
- A conjoint analysis that asks survey respondents to (1) assign relative weights and absolute scores to electricity attributes (e.g. bill level and emissions), and (2) rank electricity policies made up of such attributes (Green, 1984). To analyze the ranking data (e.g. 1 = least preferred, ..., 10 = most preferred), one can use OLS or ordered-logit regression (Greene and Hensher, 2010).

A.2. Recent estimates

To benchmark our WTP estimates, we select a sample of 16 publications based on the following criteria: (1) they are primarily studies on fuel switching and renewable resources; (2) they should preferably have been published within the last five years; (3) they should preferably be for OECD countries with per capita incomes comparable to those of Hong Kong; and (4) they should encompass the approaches described above.

As shown in Table A1, 13 of the 16 selected studies estimate WTP for alternative fuels to displace coal. The remaining three studies consider WTP for a general reduction of emissions. Among the 15 studies that use the CVM, seven use the choice-experiment approach.

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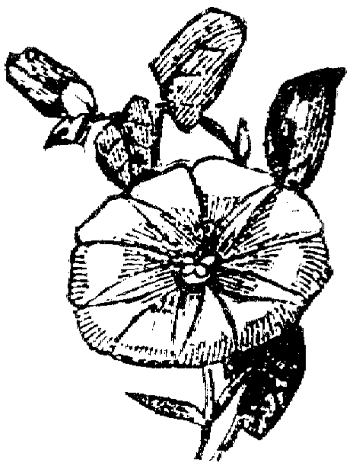
Three observations can be made from these studies. First, collecting CVM data via a choice experiment is a common approach for estimating WTP for an emissions reduction. Second, the WTP estimates are diverse, ranging from US$19 to US$1,812 per year. Finally, the WTP estimates for nuclear generation range from US$19 to US$761 per year and are generally less than those for natural-gas-fired generation; the latter range from US$133 to US$1,812 per year. These observations suggest that households are willing to pay for cleaner air and that their WTP is lower for nuclear generation than for natural-gas-fired generation.

Appendix B. Statistical Approach

B.1. Basic regression model

Respondents may respond ''yes,'' ''not sure,'' or ''no'' to a question regarding their acceptance of an emissions reduction policy that has bill increase consequences. For estimation purposes, we code ''yes'' as ''1,'' ''not sure'' as ''2,'' and ''no'' as ''3''. Since a ''yes'' (''no'') response reflects a sufficiently large positive (negative) sentiment deviation from being ''not sure,'' there is a natural ordering of these three responses. Our empirical analysis therefore begins with an ordered-logit regression to characterize household support for the various scenarios of emissions (E) and bills (B) that correspond to alternative emissions reduction policies (Greene and Hensher, 2010).

With no loss in generality, let $E = 1$ and $B = 1$ represent the normalized emissions and bill level currently faced by the respondent. Thus, our estimate of the *relative* bill increase that the respondent is willing to pay for an



emissions reduction of ΔE is a percent increase from the respondent's current bill level.

Let $Y_k \leq j$ denote the response of the kth respondent to an (E, B) pairing for $j = 1$ (''yes'') and $j = 2$ (''not sure''). Further let p_{jk} denote the probability that $Y_k = j$, and let P_{jk} denote the probability that $Y_k \leq j$. Hence, $P_{1k} = p_{1k}$, $P_{2k} = p_{1k} + p_{2k}$, and $1 - P_{2k} = p_{3k}$. Then, $O_{jk} = P_{jk}/(1 - P_{jk})$ is the odds that $Y_k \leq j$, and the natural logarithm of those odds, or $\ln[O_{jk}]$, is the dependent variable in our basic ordered-logit regression model.

For expositional purposes, this basic model includes only three independent variables: E, B, and a binary status quo variable S that is equal to unity when $E = 1$ and $B = 1$, and is zero otherwise:

$$\ln[O_{jk}] = \alpha j + \phi S + \theta E + \beta B \qquad (1)$$

We subsequently introduce nonlinearity and the respondent's demographic characteristics into the equation. Since $O_{1k} \leq O_{2k}$, it follows that $\alpha_2 \geq \alpha_1$.

Our survey data suggest that Hong Kong residents generally prefer cleaner air and lower electricity bills. We accordingly hypothesize that $\theta < 0$ and $\beta < 0$. It would similarly follow that any improvement in the status quo, which implies lower emissions and/or lower bills, or a change from $S = 1$ to $S = 0$, would increase the odds that the policy change will be viewed favorably by a respondent. Thus our third hypothesis is $\phi < 0$.

The right-hand side of Eq. (1) is the systematic portion of respondent k's random-utility function (Greene and Hensher, 2010, Chapter 3) from which one can infer the respondent's WTP for a reduction in emissions that is paid for through a higher electricity bill. To see this point, consider an emissions reduction $\Delta E < 0$ from the status quo level of $E = 1$. Given a respondent's utility level under the status quo, the maximum percent bill increase that the respondent would be willing to pay is:

$$W_S = \frac{-\phi \Delta S - \theta \Delta E}{\beta} > 0 \qquad (2)$$

The term $-\phi \Delta S$ appears in Eq. (2) because the new emissions level of $E < 1$ implies a change from the status quo, resulting in

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$\Delta S = -1$. We find $W_S > 0$ because in accordance with our hypotheses $\phi < 0$, $\theta < 0$, $\Delta E < 0$ and $\beta < 0$.

Eq. (2) likely overstates a respondent's eventual WTP for ΔE because the status quo bias is only a transitory phenomenon: once the respondent has adapted to the new emissions level, ΔS becomes zero. Hence, we compute the WTP based on:

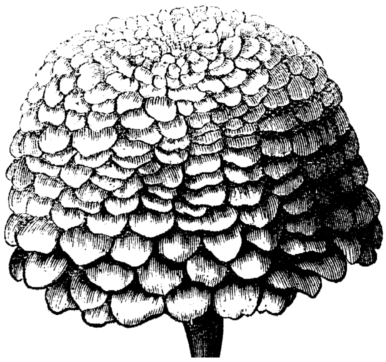
$$W = -\Delta E\left(\frac{\theta}{\beta}\right) > 0 \quad (3)$$

as similarly done in our prior research on residential outage-cost estimation (Hartman et al., 1991). This WTP estimate is more reflective of the respondent's stable tradeoff between emissions and bill levels than the one portrayed by Eq. (2).

B.2. Estimation strategy

Our basic model may not fit the survey data well because it does not consider demographics and the possibility of nonlinear relationships. Moreover, the support for using natural-gas-fired generation to displace coal-fired generation can vastly differ from that for nuclear generation, because respondents may perceive great disparities in the degree of risk to their safety entailed in the two generation technologies. Hence, we employ the following process to identify an empirically reasonable regression model:

- Step 1: Apply the maximum likelihood method (PROC LOGISTIC in SAS (Allison, 2012)) to the response data for a given fuel type (e.g. natural gas) to estimate the quadratic specification that is a second-order approximation of an unknown nonlinear function of (E, B).
- Step 2: After excluding highly insignificant terms in the quadratic regression in Step 1, construct a nested model that



encompasses the two fuel-specific regressions:

$$\begin{aligned}\ln[O_{jk}] = \alpha_j + \phi S + \theta_1 E \\ + \theta_2 E^2(1-N) \\ + \theta_3 EN + \beta_1 B \\ + \beta_2 BN\end{aligned}$$

where N is equal to unity if nuclear generation were to displace coal-fired generation, and is zero otherwise.

- Step 3: Introduce the customer characteristics listed in Table 3 to account for their effects on the logarithm of the odds O_{jk}. The demographic variables that enter into our final model are based on the results of a step-wise regression procedure and the plausibility and statistical significance of their estimated coefficients. This results in Model 1 in **Table B1**

$$\begin{aligned}\dot{\ln}[O_{jk}] = \alpha_j + \phi S + \theta_1 E \\ + \theta_2 E^2(1-N) \\ + \theta_3 EN + \beta_1 B \\ + \beta_2 BN + \eta_1 BX_{1k} \\ + \eta_2 BX_{2k} + \eta_3 BX_{3k}\end{aligned}$$

where X_{1k} = respondent k's years of age, X_{2k} = respondent k's family size, and X_{3k} = respondent k's number of years living in Hong Kong.

- Step 4: In the course of estimating the parameters of Model 1, we determine that the proportional-odds assumption of ordered logit is decisively rejected ($\alpha = 0.01$) for our sample data. In light of this rejection, we estimate two binary logit models. The first model combines the ''not sure'' and ''no'' responses into one category. The second model excludes the ''not sure'' responses and reflects a ''yes'' versus a ''no'' response. The latter omission gains credence from the fact that ''not sure'' comprises, for the most part, fewer than 5 percent of the responses. Indeed, the relative paucity of ''not sure'' responses deterred us from either estimating a multinomial-logit regression, or a binary logit that estimates the odds of ''not sure'' versus either ''yes'' or ''no.'' The parameter estimates and their p-values (in parenthesis) for these models, Model 2 and Model 3, respectively, are also shown in Table B1.

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Table B1: Logistic Regression Results Obtained by Maximum Likelihood Estimation; *p*-Values in ( ).

Variable	Model 1: Eq. (5) With Three Responses: 1 (''Yes''), 2 (''Not Sure''), 3 (''No'')	Model 2: Eq. (5) With Two Responses: 1 (''Yes''), 2 (''Not Sure'' or ''No'')	Model 3: Eq. (5) With Two Responses: 1 (''Yes''), 2 (''No'')
Total number of observations	5,439	5,439	5,194
Number [share] of 1 (''yes'') opinions	2,068 [0.384]	2,086 [0.384]	2,086 [0.402]
Number [share] of 2 (''not sure'') opinions	245 [0.045]		
Number [share] of 3 (''no'') opinions	3,108 [0.571]		
Number [share] of 2 (''not sure or no'') opinions		3,353 [0.616]	
Number [share] of 2 (''no'') opinions			3,108 [0.598]
Log likelihood with intercepts only (L_0)	−4,497.92	−3,621.09	−3,499.00
Log likelihood with intercepts and covariates (L_1)	−4,035.63	−3,176.51	−3,037.71
McFadden pseudo $R^2 = 1 - L_1/L_0$	0.1028	0.1228	0.1318
Intercept for response = 1 (''yes'')	4.290 (<.001)	4.283 (<.001)	4.583 (<.001)
Intercept for response = 1 (''yes'') or 2 (''not sure'')	4.512 (<.001)		
$S = 1$ if the (E, B) combination is the status quo; 0, otherwise	−2.493 (<.001)	−2.544 (<.001)	−2.641 (<.001)
E = emissions level normalized at 1.0	11.670 (<.001)	11.059 (<.001)	12.197 (<.001)
B = electricity bill normalized at 1.0	−5.930 (<.001)	−5.682 (<.001)	−6.142 (<.001)
$E^2 (1 - N)$ = normalized emissions level squared × $(1 - N)$; where $N = 1$ if the response is for nuclear generation; 0 otherwise	−7.977 (<.001)	−7.547 (<.001)	−8.322 (<.001)
$E\,N$ = normalized emissions level × N	−12.722 (<.001)	−12.010 (<.001)	−13.253 (<.001)
$B\,N$ = normalized bill × N	3.387 (<.001)	3.113 (<.001)	3.514 (<.001)
BX_1 = normalized bill × respondent's age	0.006 (0.005)	0.002 (0.343)	0.005 (0.021)
BX_2 = normalized bill × respondent's family size	−0.083 (0.006)	−0.055 (0.076)	−0.088 (0.006)
BX_3 = normalized bill × respondent's years of living in Hong Kong	−0.048 (<.001)	−0.045 (<.001)	−0.050 (<.001)

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B.3. WTP Inferences

Based on Hartman et al. (1991) and evaluated at $\Delta S = 0$, Eq. (5) implies that respondent k's marginal utility of E is $(\theta_1 + 2\theta_2(1-N)E + \theta_3 N)$ and that of B is $(\beta_1 + \beta_2 N + \eta_1 X_{1k} + \eta_2 X_{2k} + \eta_3 X_{3k})$. Based on Eq. (3) and evaluated at $E = 1$, respondent k's *relative* WTP for $\Delta E < 0$ is:

$$W_k = \frac{-\Delta E[\theta_1 + 2\theta_2(1-N)E + \theta_3 N]}{\beta_1 + \beta_2 N + \eta_1 X_{1k} + \eta_2 X_{2k} + \eta_3 X_{3k}} \tag{6}$$

To empirically implement Eq. (6), we replace (θ_1, θ_2, θ_3, β_1, β_2, η_1, η_2, η_3) with their maximum likelihood estimates (q_1, q_2, q_3, b_1, b_2, h_1, h_2, h_3). For simplicity, we use Model 3 in Table B1 for our WTP calculation. Using Model 1 or Model 2 does not materially alter our WTP estimates because all three models have similar slope-coefficient estimates.

Now, our WTP estimate in percent bill increase for respondent k is:

$$W_k = -\Delta E\left(\frac{q}{gk}\right) \tag{7}$$

where $q = q_1 + 2q_2(1-N)E + q_3 N$, and $g_k = b_1 + b_2 N + h_1 X_{1k} + h_2 X_{2k} + h_3 X_{3k}$. Since ΔE is a known constant, the variance of W_k is:

$$\mathrm{var}(W_k) = (\Delta E)^2 \mathrm{var}\left(\frac{q}{gk}\right) \tag{8}$$

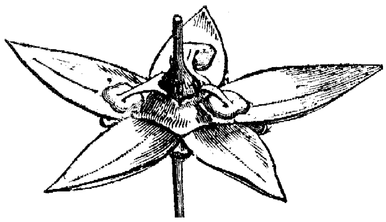
Since (q/g_k) is the quotient of two random variables, we use the approximation formula in Boes et al. (1974, p. 181) to compute $\mathrm{var}(q/b_k)$. An estimate of the average WTP of our K respondents is:

$$A = \frac{\Sigma_k W_k}{K} \tag{9a}$$

An estimate of the average WTP's variance is:

$$U = \frac{\sum_k \mathrm{var}(W_k)}{K} \tag{9b}$$

We use the average WTP estimate A given by Eq. (9a) and



its variance U given by Eq. (9b) to construct the 95 percent confidence interval for the true but unobservable average WTP for a given ΔE. Shown in Fig. 3, this confidence interval helps determine household support for any given emissions reduction policy. To see this point, suppose the WTP estimate's upper bound is a $Y\%$ bill increase for $\Delta E = Z\% < 0$ achieved through natural-gas-fired generation. If the utilities' projected bill increase is $X\% > Y\%$, we infer that there is a lack of public support for using natural-gas-fired generation to achieve $\Delta E = Z\% < 0$.

We covert our WTP estimate A, which is given in terms of a percent bill increase, to dollars per year. Let Z_k denote respondent k's average monthly bill (HK$/month). Our annual dollar estimate of respondent k's WTP for ΔE is:

$$C_k = -12 Z_k W_k \tag{10a}$$

The estimated variance of C_k is:

$$k = 144 Z_k^2[\mathrm{var}(W_k)]. \tag{10b}$$

As C_k and V_k are estimates that vary by respondent, an estimate for the mean WTP for K respondents is:

$$C = \frac{\sum_k C_k}{K} \tag{11a}$$

An estimate for the mean variance is:

$$V = \frac{\sum_k V_k}{K} \tag{11b}$$

which is used to construct the 95 percent confidence interval for C in Fig. 4.

B.4. Logistic regression

Table B1 reports our regression results and Model 3 is used for our WTP inferences. The goodness of fit of Model 3 is measured by the conservative McFadden pseudo R^2 of 0.132, implying a 13.2 percent improvement of the likelihood function by the non-intercept regressors. This seemingly low R^2 is expected as we use a simple model to characterize the data-generation process for a large cross-sectional sample of response data.

We interpret Model 3's highly statistically significant ($\alpha = 0.01$) slope-coefficient estimates as follows:

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- The coefficient estimate for S is -2.641, suggesting strong household sentiment against the status quo.
- The marginal effect of a normalized increase in emissions from generation on the logarithm of the odds is $[12.197 - 2 \times 8.322(1 - N) \times E - 13.253 \times N] < 0$ at $E = 1$ and $N = 0$ or 1. Hence, any such increase in emissions tends to reduce support for a given (E, B) combination.
- A bill increase tends to reduce support of a given emissions level, because at $B = 1$, the marginal effect of an increase in the normalized bill on the logarithm of the odds is $(-6.142 + 3.514 \times N + 0.005 \times$ respondent's age $- 0.088 \times$ respondent's family size $- 0.050 \times$ respondent's years in Hong Kong$) < 0$ for $N = 0$ or 1.
- The marginal effect of age on the logarithm of the odds is 0.005 at $B = 1$, implying that an older respondent tends to be more supportive of an (E, B) combination than is a younger respondent.
- The marginal effect of family size on the logarithm of the odds is -0.088 at $B = 1$, implying that a respondent with more family members tends to be less supportive of an (E, B) combination than is one with fewer family members.
- The marginal effect of years of Hong Kong residency on the logarithm of the odds is -0.050 at $B = 1$, implying that those with lengthier tenure in the territory tend to be less supportive of an (E, B) combination than those with shorter tenure.

■

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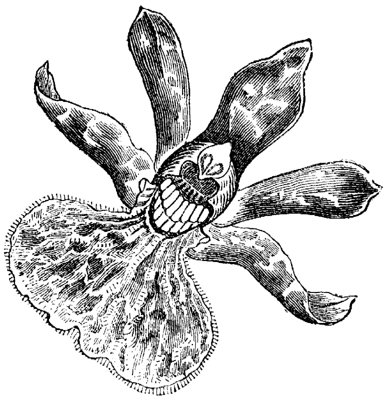

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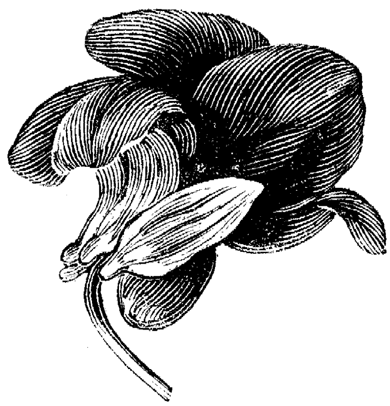

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Endnotes:

1. Our empirical evidence's relevance is underscored by Hong Kong's population that exceeded those of 37 of the 50 states in the U.S. in 2012 (http://www.census.gov/popest/data/state/totals/2012/), eight of the 10 Canadian provinces in 2013 (http://www.stats.gov.nl.ca/statistics/population/PDF/Annual_Pop_Prov.PDF), and nine of the 34 OECD countries in 2010 (http://www.oecd-ilibrary.org/docserver/download/3011041ec009.pdf?expires=1389405952&id=id&accname=guest&checksum=7DDEDE2EE2EDFB46DBA8117E187B45A2).

2. http://www.eea.europa.eu/data-and-maps/indicators/electricity-production-by-fuel-1/electricity-production-by-fuel-assessment-2; http://www.eia.gov/todayinenergy/detail.cfm?id=13731; http://www.originenergy.com.au/energymix

3. Hong Kong is one of the most densely populated cities in the world. With an average residential real estate price of about US$10,000 per m^2 (http://www.scmp.com/business/economy/article/1331009/hong-kong-peg-us-dollar-blamed-citys-soaring-property-prices), large-scale development of on-shore solar and wind energy is prohibitively expensive. Moreover, it is politically infeasible due to a severe shortage of affordable housing (http://www.scmp.com/comment/insight-opinion/article/1304113/hong-kong-must-grapple-question-housing-supply). Additional information about Hong Kong's renewable energy potential is available at http://re.emsd.gov.hk/english/gen/overview/over_faq.html.

4. http://www.news.gov.hk/en/categories/environment/html/2013/11/20131122_125319.shtml

5. http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/cleaning_air_atroad.html

6. As shown in Appendix B, our analysis focuses on the proportion of respondents supporting an emissions-reduction policy scenario. Thus, our sample is sufficiently large, beyond the size requirement of 1,061 (1,849) observations to achieve a ±3% error margin at the 0.95 (0.99) confidence level (Cochran, 1977). Moreover, it is a representative sample, as suggested by the sample means for the key demographics of age, education and family size, which are within 5% of their respective population means based on Hong Kong's 2011 (census http://www.census2011.gov.hk/pdf/summary-results.pdf).

7. As shown in Appendix A, the CVM is commonly used to for WTP estimation.

8. Both the English and Chinese versions of the questionnaire are available from Alice Shiu (afshiu@polyu.edu.hk).

9. See http://www.thestandard.com.hk/news_detail.asp?pp_cat=30&art_id=118938&sid=35103473&con_type=3&d_str=20120118&isSearch=1&sear_year=2012

10. See http://www.news.gov.hk/en/categories/environment/html/2013/11/20131122_125319.shtml

11. See http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/cleaning_air_atroad.html

The findings support the calls to revise the government's proposal for reducing emissions from coal-fired generation.

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