Impact of the First-Time Car Buyer Program on the Environmental Cost of Air Pollution in Bangkok

Attavanich, Witsanu

Faculty of Economics, Kasetsart University

17 April 2017

Impact of the First-Time Car Buyer Program on the Environmental Cost of Air Pollution in Bangkok

Witsanu Attavanich, Ph.D.

Assistant Professor

witsanu.a@ku.ac.th

Department of Economics

Faculty of Economics, Kasetsart University

Selected paper prepared for presentation at the Kuala Lumpur Seminar Series hosted by the World Bank's Development Research Group. Kuala Lumpur, Malaysia, April 20, 2017

Impact of the First-Time Car Buyer Program on the Environmental Cost of Air Pollution in Bangkok

1. Introduction

Whereas cities in high-income countries have seen continuous improvements in air quality over the last decade, 98 percent of cities in low- and middle income countries with more than 100,000 inhabitants do not meet World Health Organization (WHO) air quality guidelines. Past studies revealed that people living in these urban areas highly likely faced the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases as urban air quality declines (e.g., WHO, 2016; 2017; Cohen et al., 2004) causing an estimated 6.5 million deaths in 2012 making it the largest single environmental health risk WHO (2016). Bangkok has been one of cities in middle income countries facing the problem of air quality. According to the data from the Pollution Control Department (2016), its air pollution have exceeded the WHO guidelines for several pollutants such as the particulate matter 10 micrometers or less in diameter (PM_{10}), ozone (O_3), and nitrogen dioxide (NO_2). Similar finding was discovered by Cady-Pereira et al. (2017) who studied air pollution above 18 of the world's megacities since 2013 and found 14 percent of ozone observations above harmful threshold in Bangkok.

Past studies also revealed that each 10 micrograms per cubic meter ($\mu g/m^3$) increase in PM_{10} in Bangkok is associated with a 1.25 percent increase in all-cause mortality, which is higher than Hong Kong, Shanghai, and Wuhan (Wong et al., 2008) and several Western countries (Katsouyanni et al. 2001). It has been recognized that vehicle emissions are overwhelmingly the primary source of air pollution in Bangkok especially the period of traffic congestion (e.g., Chuersuwan 2008). Recently, Bangkok is ranked second amongst the top 10 cities of the world which have the worst traffic according to 2016 TomTom Traffic Index (TomTom, 2017). From 2011 to 2016, the number of vehicle registered in Bangkok increased from 6.8 million units to 9.4 million units, while the existing road system can accommodate only 1.5 million vehicles (Bangkok Post, 2016).

Despite facing with the air pollution caused by the worst traffic congestion for several decades, the Thai government launched a tax refund policy for first time car buyers, which will be later called the "first-time car buyer program" between 16 September 2011 and 31 December 2012. The program aimed to give an opportunity to low-to-middle income people to own their first car with discounted price, stabilize the economy by increasing the domestic purchasing powers, increase the tax revenue, and help the automotive industry recover in the wake of severe floods during September 2011 to March 2012. Under this program, the government committed to provide tax rebates equivalent to 10 percent of the maximum vehicle purchase price of $28,196 dollars with the maximum engine size of 1.5 liter.[1] The rebates are made available after five years of continuous single-ownership of the vehicle. At the end of the program, 1.26 million cars registered to the program exceeding the target set at 0.75 million cars nationwide (Excise Department, 2013). It was anticipated that at least 30 percent of cars registered to the program would enter to the limited road system in Bangkok and its vicinity (Thai PBS, 2012).

Past studies evaluated the impacts of the first-time car buyer program. Excise Department (2013) predicted that the program could increase the annual GDP growth of 1.06 percent, or approximately $3.82 billion during the period of implementation. Since the program incentivized consumers to buy cars sooner than their plan, Bureau of the Budget (2014) expected that the program could reduce the future demand for new cars in 2013 about 9.5 percent and it expected to increase the stock of car approximately 0.2 million units due to buyer's inability to repay the bank loan. The listing prices of used car sold in the market were expected to drop between 5-10 percent (Bureau of the Budget, 2014; Noparumpa and Saengchote, 2017). Lastly, Phetcharat, Buntan and Chintarat, (2015) found that traffic volume would increase by 8.22 % on the highways in Bangkok and the peak-hour speed will decrease by 3.26 and 5.76 % respectively for AM and PM peak hours.

While previous studies measured the impacts of the first-time car buyer program on several aspects, important questions remain unanswered. Among them is whether the program had a meaningful impact on the environmental cost of air pollution in Bangkok. The objectives of this study are therefore to empirically examine the impact of the first-time car buyer program on environmental cost of air pollution in Bangkok using hourly air pollution records from monitoring stations. Pollution levels are compared before and after the program for five major pollutants. The analysis controls for possible confounding factors by restricting the sample to a narrow time window around the implementation of the program and by using the interrupted time series analysis (ITSA). The changed concentration of each pollutant is then converted to

[1] The Exchange rate is equal to 35.4659 Thai baht/US dollar.

monetary values using the subjective well-being (SWB) approach with happiness data and the instrumental variable technique to address the endogeneity problem.

This article contributes to the impact evaluation literature in several aspects. Firstly, the findings from this study can shed some light to the Thai government and public sector for the first-time car buyer program's social net benefit by adding environmental cost to the consideration. Some see the program as an important instrument to stimulate economic growth, where as other disagreed to the program due to negative externalities such as air pollution and traffic congestion. Results from this study combining with those from previous studies can be used for lessons learned for designing future public programs. Secondly, the current study is among the first to assess the willingness to pay for reducing air pollutants simultaneously in Bangkok. Lastly, approaches used and the results from this article can help governments to gauge the monetary value of better air quality so as to compare it with the cost of environmental regulations and benefits of public programs directly or indirectly affecting air quality.

The balance of the paper is organized as follows. The following section provides background on the first-time car buyer program. The third section introduces data and methodologies used to measure the effect of the first car buyer program on air quality and how to value air quality using happiness data. The fourth section presents empirical results. The final section provides concluding remarks and policy implications.

2. Background of the First-Time Car Buyer Program and Air Quality in Bangkok

During the program implementation, Thailand faced with 2011 severe flood ranked as the world's fourth costliest disaster (Haraguchi and Lall, 2014; Zhang 2013) and subsequently seven major industrial estates were inundated in water disrupting the car production. All major car factories had to stop their operation at the beginning of October 2011 and they were fully resumed their production at the end of March 2012 (Haraguchi and Lall, 2014). As a result, this study uses 1 April 2012 as a starting date of the first car buyer program instead of 16 September 2011. Because of the flood disaster delaying the car production to meet the demand, the government decided to extend the delivery date of car to September 2015, while approximately 99 percent of participating cars were delivered in March 2014. Figure 1 illustrates the number of new registered cars before and after the program implementation in Bangkok. We can observe that overall the number of registered cars during April 2012 – March 2014 were higher than those during January 2009 – March 2012.

[Figure 1]

2011 severe flood also affected the air quality in Bangkok area since all areas in Bangkok were flooded shutting down the road system during 27 October to 5 December 2011. Air quality in Bangkok is recorded by the automated monitoring stations distributed throughout Bangkok and maintained by the Pollution Control Department (PCD). Stations reports hourly measures of particulate matter 10 micrometers, nitrogen dioxide, ozone, carbon monoxide, and sulfur dioxide. These measures are widely used in scientific publications and are reported to the public in the form of the Air Quality Index.

Figure 2 plots average hourly pollution levels during 1 April 2010 – 31 March 2014. Average hourly pollution levels were constructed by averaging over all monitoring stations. Levels of PM_{10}, NO_2, and O_3 continually increased, while CO decreased and SO2 decreased in the early of 2011 and then increase. Levels of all pollutants varied widely across hours, days, and months. The vertical line indicates the implementation of the first car buyer program on 1 April 2012. There is visible increase in PM_{10}, NO_2, and O_3 and no visible increase in CO and SO_2.

[Figure 2]

The empirical analysis focuses on the period 1 April 2010 – 31 March 2014, and 4-year symmetric window around the implementation of the first car buyer program. Table 1 shows pollution levels during this period, as well as, temperature, rainfall, relative humidity, and wind speed, collected in the same station. No stations closed or were moved during this period. Figure 3 plots pollution levels across hours of the day. The figure reveals substantial variation in pollution levels over the course of the day with peak levels reached during the morning and evening commute excepting for ozone, which peaks during the late afternoon because ozone production requires warmth and sunlight (Seinfeld and Pandis, 1998; Davis, 2008).

[Table 1]

[Figure 3]

The rapid changes over the course of the day indicate that air quality in Bangkok responds quickly to changes in emissions. This is critical in the analysis because it means that it is possible to make inferences about changes in emissions by comparing air pollution levels within a relatively narrow time window. With the average wind speed in Bangkok reported in table 1 (1.22 meters per second), pollutants do not likely remain in city atmosphere for more than 24 hours. Although several sources believe that the program could lower the air quality in Bangkok, no methodological detailed studies quantify the impact of the first car buyer program.

3. Methodology and Data

3.1 Measuring the Effect of the First Car Buyer Program on Air Quality

In the main specification, average hourly air pollution, P_t, is regressed on $First_t$, an dummy (indicator) variable capturing the program intervention (pre-intervention periods 0, otherwise 1), the interaction between *First* and time trend ($T*First_t$), and a vector of covariates $\mathbf{Z_t}$ shown in equation (1):

$$P_t = \delta_0 + \delta_1 T + \delta_2 First_t + \delta_3 T * First_t + \mathbf{Z}_t'\boldsymbol{\eta} + \mu_t \quad (1)$$

The coefficient of interest, δ_2 and δ_3, are the effect of the first car buyer program (*First*) on air pollution. Following Davis (2008), the vector of covariates, $\mathbf{Z_t}$, includes dummy variables for month of the year, week day, hour of the day, as well as interactions between weekday and hour of the day. In addition, $\mathbf{Z_t}$ includes weather variables including temperature, rainfall, relative humidity, wind speed and their squared terms plus the dummy variables capturing the direction of wind blowing to south east, southwest, northeast, or northwest. This study also add the dummy variable capturing the severe flood event during 27 October 2011 – 5 December 2011 to vector $\mathbf{Z_t}$**.** The air quality in Bangkok during the severe flood was expected to improve. Summary statistics of all variables are provided in the supplemental document table A1.

The specification in equation (1) is derived from the notion of an interrupted time series analysis (ITSA) offering a quasi-experimental research design with a potentially high degree of internal validity (Shadish, Cook, and Campbell, 2002). ITSA has been widely used in program evaluation literature such as regulatory actions (Muller, 2004; Stallings-Smith et al., 2013; Yinon and Thurston, 2017), pollution (Pearson, Campbell and Maheswaran, 2016), health concerns (Gillings, Makuc, and Siegel, 1981; Dayer, 2015). Prais–Winsten regression introduced by

Prais–Winsten (1954) is utilized for estimation.[2] In this technique, the errors are assumed to follow a first-order autoregressive process ($\mu_t = \rho\mu_{t-1} + e_t$). The e_t are independently and identically distributed as N(0,σ^2). Instead of estimating each pollutant separately, as a robustness check, this study also estimates all pollutants simultaneously using the seemingly unrelated regression (SUR) proposed by Zellner (1962) to address the possible correlation of error terms across equations.

3.2 Valuing Air Quality Using Life Satisfaction Data

The estimated changes in concentration of each pollutant in the previous section is then monetarized using the subjective well-being (SWB) approach with life satisfaction data. SWB approach was introduced to address some weaknesses of traditional approaches including stated preference approaches (SPAs) and revealed preference approaches (RPAs). Studies (e.g., Clark and Oswald, 1994; Welsch, 2002, 2006; Levinson, 2012) revealed several advantages of SWB over SPAs and RPAs. For example, in the SWB method, interviewees will not be asked to value the environmental quality which they have no experiences and researchers' misunderstanding in setting the scenarios will be removed reducing strategic biases and framing problems. Also perfectly competitive market assumption is not assumed in the SWB method. For valuing environmental quality, travel-cost and many hedonic models may underestimate the value of air quality since people most averse to air pollution choose to visit and live in clean places, (Levinson, 2012).

To assess the environmental costs based on the SWB method, household's life satisfaction was estimated as the functions of income, environment and other covariates. Using the coefficients for the environment and income, it is possible to calculate utility constant trade-off ratios between the environment and income. The approach has been widely used to value air quality (e.g., Welsch, 2002, 2006; Di Tella and MacCulloch, 2007; Luechinger, 2009; Levinson, 2012; Zhang, X., Zhang, X. and Chen, X., 2017). In the main specification, happiness score of

[2] This study cannot use the regression discontinuity design since there was no abrupt change in pollution levels since each consumer can buy his/her car at different date during the program implementation and car companies can deliver cars as late as 31 September 2015.

household i in province j, H_{ij}, is regressed on the pollutant i in province j, P_{ij}, income (in log form[3]) of household i in province j, and a vector of covariates $\mathbf{X_{ij}}$ shown in equation (2):

$$H_{ij} = \alpha P_{ij} + \gamma \ln Y_{ij} + \mathbf{X}'_{ij}\boldsymbol{\beta} + \varepsilon_{ij} \quad (2)$$

The coefficients α and γ capture the effect of pollution and income on life satisfaction, respectively. According to the suggestion from studies, the vector of covariates, $\mathbf{X_{ij}}$, includes respondent's gender age, marriage status and number of household members, whether the respondent has the Thai nationality, whether the respondent graduated at least bachelor degree, whether the respondent is employed, stated health condition (good, fair, and bad), whether the respondent lives in municipal area. In addition, $\mathbf{X_{ij}}$ includes weather variables including temperature and rainfall. Lastly, regional dummy variables (Bangkok, North, Northeast, South, and Central) are added in the model to control for time-invariant omitted-variable bias and accommodate regional specific differences in the individuals' personal characteristics. This study uses several estimation techniques including ordinary least square (OLS) and ordered probit with/without an instrumental variable with different specifications to address the endogeneity bias as recommended in the literature.[4] Following Luttmer (2005), this study instruments for household incomes using the respondents' occupation. Respondents who work in occupations with high wages are likely to have higher household incomes and are therefore more likely to report higher levels of life satisfaction.

The estimated marginal willingness to pay (WTP) for each pollutant is then estimated using the formulation in equation (3) evaluated at the annual mean income of households living in Bangkok area in 2012 (National Statistical Office, 2014).

$$\frac{\partial Y}{\partial P}\Big|_{dH=0} = -\frac{\hat{\alpha}}{\hat{\gamma}}\bar{Y} \quad (3)$$

The main source of data was taken from the life satisfaction survey jointly conducted by the National Statistical Office, Healthy Public Policy Foundation, and Thai Health Promotion Foundation in 2012 with 54,100 samples distributed in all provinces of Thailand. The survey in

---

[3] Log form of income captures the law of diminishing marginal utility.
[4] While more income may make people happier, happier people may earn higher incomes.

2012 is the first attempt to collect the happiness data in Thailand and it is the only one year available. The provincial level air quality data were collected from the technical reports of Pollution Control Department, Ministry of Natural Resources and Environment. In addition, the data on climate conditions were obtained from the Meteorological Department.

Table 2 provides summary statistics of variables used to estimate the willingness to pay. Nationally, in 2012, the mean of life satisfaction score was equal to 7.72 out of 10. A majority of respondents were female and married, and had age during 40-49 years old, Thai nationality, good health status, and lived in non-municipal area. The mean number of household members was 3.73 persons/household and had mean annual household income equal to $4,679 dollar. The national mean concentrations of PM_{10}, NO_2, O_3, CO, and SO_2 were equal to 37.39 μg/m^3, 12.97 ppb, 20.23 ppb, 0.60 ppm, and 2.75 ppb, respectively. For weather information, the annual mean temperature and total rainfall in 2012 were equal to 26.86°C and 164.50 millimeters, respectively.

4. Empirical Results

4.1 The Effect of the First Car Buyer Program on Air Quality

Equation (1) is first estimated for two different time windows including the period between 1 October 2009 – 31 September 2014 and 1 April 2010 – 31 March 2014. Windows smaller than 2 years are not considered because it becomes difficult to credibly control for seasonal variation (Davis, 2008). Limiting the sample to include observations from a relatively narrow range of dates is important because it helps disentangle the effect of the first car buyer program from the effect of other time varying factors that influence air quality in Bangkok. Following Nerlove, Grether, and Carvalho (1979), this study tested the unit root of the residual for each pollutant's equation and found that the residual of each equation is stationary excluding the possibility of spurious bias.

For the period during 1 October 2009 – 31 September 2014, estimated small changes in concentration of pollutants were observed. However, when we performed the estimation with the time window during 1 April 2010 - 31 March 2014, the larger impacts of the first car buyer program were revealed. This may be explained by the fact that approximately 99 percent of participating cars were delivered within 31 March 2014. Table 3 shows the estimated coefficients for each pollution specification using the Prais-Winsten regression. For brevity, we omit to present coefficients of dummy variables for month of the year, hour of the day, as well as interactions between weekday and hour of the day and interactions between wind speed and wind direction. More details are provided in supplementary tables A2-A6 with different specifications.

Overall, we can observed that during the period before the program was launched, pollution levels tended to decline overtime excepting for NO_2. At the first day of program (intervention point), levels of PM_{10} and SO_2 dropped, while the level of NO_2 increased and no changes of O_3 and CO were observed statistically. The reduction of PM_{10} and SO_2 and unchanged levels of O_3 and CO could come from the fact that car producers postponed their car delivery to buyers due to 2011 severe flood and the fact that each buyer can buy his/her car at different point in time. Explanation of the increase in NO_2 level is quite complex because there may interact with other nitrogen oxides. We also observed that after the program implementation, the concentrations of all pollutants (except for NO_2) were increasing over time, which could be caused by the increase in the number of cars entering to the program. Air quality was improved during the period of severe flood. In general, the levels of air pollution during the weekday were higher than those during the weekend. Similar to previous studies, weather conditions, relative humidity, and wind speed were founded to affect the air quality.

Using estimated coefficients from table 3, we estimate the average concentration levels of pollutants with and without program implementation and test whether they are different as shown in table 4. Overall, we can observe that concentration levels of all pollutants (except for NO_2) were increased as a result of the first car buyer program. Changes in concentration levels of PM_{10}, O_3, CO, and SO_2 were equal to 8.3542 $\mu g/m^3$, 8.5358 ppb, 0.1334 ppm, and 2.3831 ppb, respectively, while concentration level of NO_2 was dropped 0.8549 ppb with 1 percent level of significance.

4.2 Willingness to Pay for Air Quality

This section estimates the value of willingness to pay per unit for each pollutant, which will be used to convert changed concentration levels of pollutants to monetary value using the SWB method with life satisfaction data. Table 5 provided estimated coefficients of selected variables in models from the linear regression with the instrumental variable. The instrumental variable capturing whether respondents' occupation has high income was tested for the good IV. Test for excluded instruments rejected the null hypothesis and Kleibergen-Paap rk LM statistic revealed that the model is identified. The Stock-Wright LM S statistic also showed that the estimated coefficient and overidentifying restrictions are valid. Therefore, the selected IV is valid for estimation.

Results reveal that income level is positively correlated to the life satisfaction score, while the pollution level is negatively correlated to the happiness. Only the coefficient of SO_2 is not significant. Respondents having female gender, retired, single status, Thai nationality, education less that Bachelor degree, job employed, good health, less number of household members, and house in the non-municipal area tend to have higher scores of happiness than others. Similar to Levinson (2012), we found that weather conditions and their variability statistically affect the life satisfaction.

Using the estimated coefficients of income [γ] and pollution [α] evaluated at $16,643 dollar per year, which was the annual mean income of households living in Bangkok area of in 2012, the estimated values of WTP for a unit reduction are reported in table 6. The estimated annual household values of WTP for PM_{10}, NO_2, O_3, CO, and SO_2 are equal to $65.789 dollar per $\mu g/m^3$, $201.796 dollar per ppb, $101.312 dollar per ppb, $8,533.496 dollar per ppm, and $155.471 dollar per ppb, respectively. Consistent to previous studies (e.g., Levinson, 2012; Powdthavee, 2009), the income coefficient in IV specifications is larger than in OLS specifications and hence lower WTP values are revealed. As a robustness check, this study also provided the estimated WTP from the ordered probit using instrumental variable shown in table 6 and estimated coefficients of variables in each model are offered in supplementary table A8. Slightly different findings are revealed.

Comparing the estimated values of WTP from this paper and previous studies, we found that in general the willingness to pay in developed countries is higher than that in developing countries. For example, using the happiness data in the US, Levinson (2012) reported that the WTP values for PM_{10}, O_3, SO_2, and CO were $728 per $\mu g/m^3$, $286 per ppb, $330 per ppb, and $6,089 per ppm, respectively. Excepting for CO, WTP of other pollutants in the US were larger than those in Bangkok.

4.3 Environmental Cost of Air Pollution from the First Car Buyer Program

Assuming that all households in Bangkok were affected by the pollution generated from the first car buyer program, we multiplied the value of environmental cost per household per year for each pollutant to the total number of households in Bangkok, which were equal to 2,593,827 households. Table 7 illustrates the total environmental damages for each pollutant. By assuming the additive impacts of each pollutant on households and excluding the environmental cost generated from SO_2 due to its statistical insignificant, the value of estimated total environmental cost generated from the first car buyer program is equal to $6.173 billion dollar annually.

5. Conclusion

In September 2011, the Thai government introduced a populist program so called "the first car buyer program to stimulate economic growth and offer an opportunity to low-to-middle income people to own their first car with discounted price. As a result, there are a number of cars added to the limited road system in Bangkok worsening the traffic congestion and air quality. Although several studies evaluated the impacts of the program on several aspects, the aspect of environmental impacts from air pollution has been ignored. The objective of this study is to evaluate the impact of the first-time car buyer program on environmental cost of air pollution in Bangkok using hourly air pollution records from monitoring stations for five major pollutants and the happiness data.

Using the interrupted time series analysis, this article finds the program increased the levels of PM_{10}, O_3, CO, and SO_2 by 8.3542 $\mu g/m^3$, 8.5358 ppb, 0.1334 ppm, and 2.3831 ppb, respectively, while it decreased the level of NO_2 by 0.8549 ppb with 1 percent level of significance. The annual household values of willingness to pay (WTP) estimated from the happiness data and the ordinary least square with instrumental variable for PM_{10}, NO_2, O_3, CO, and SO_2 are equal to $65.789 dollar per $\mu g/m^3$, $201.796 dollar per ppb, $101.312 dollar per ppb, $8,533.496 dollar per ppm, and $155.471 dollar per ppb, respectively. As a result, the value of estimated total environmental cost generated from the first car buyer program is equal to $6.173 billion dollar annually.

While several studies from the governmental office revealed the positive impacts generated from the first car buyer program, the findings from this study reflects the negative view of the program and it is suggested that environmental outcomes generated from the public programs should be considered when designing policies. Lessons learned during the East Asia financial crisis in 1997 taught us that only enhancing economic growth is not sustainable way to improve economic development. Raising economic growth may be good in the short run, but racing to the bottom by worsening the environment may be bad for the society both in the short and long run. Future studies are recommended to evaluate other negative externalities created from the first car buyer program and other public program on the society since they often have not been considered.

6. References

Bangkok Post. 2016. City traffic jams burn up B97m of fuel a day. Published: 1/09/2016 at 11:55 AM. Accessed April 3, 2017 http://www.bangkokpost.com/print/1075777/

Bureau of the Budget. 2014. The first-time car buyer program. Monitoring and Evaluation Report for fiscal year 2013. Accessed April 1, 2017 http://www.bb.go.th/iWebTemp/25600401/ulmmn4554g1wfr2vjjnn3ieo191249.PDF

Cady-Pereira, K. E., Payne, V. H., Neu, J. L., Bowman, K. W., Miyazaki, K., Marais, E. A., Kulawik, S., Tzompa-Sosa, Z. A., and Hegarty, J. D. 2017. Seasonal and Spatial Changes in Trace Gases over Megacities from AURA TES Observations*, Atmos. Chem. Phys*. Discuss., doi:10.5194/acp-2017-110, in review.

Clark, A.E., Oswald, A.J. 1994. Unhappiness and unemployment. *Economic Journal* 104: 648–659.

Cohen A et al. 2004. Mortality impacts of urban air pollution. In: Ezzati M et al., eds. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. Geneva, World Health Organization: 1353 –1434.

Davis, L.W. 2008. The effect of driving restrictions on air quality in Mexico City. *Journal of Political Economy 116*(1), pp.38-81.

Dayer, M.J., Jones, S., Prendergast, B., Baddour, L.M., Lockhart, P.B. and Thornhill, M.H., 2015. Incidence of infective endocarditis in England, 2000–13: a secular trend, interrupted time-series analysis. *The Lancet 385*(9974), pp.1219-1228.

Department of Land Transport. 2016. The number of registered cars in Bangkok. Accessed April 3, 2017 http://apps.dlt.go.th/statistics_web/newcar.html

Excise Department. 2013. Summary of the first-time car buyer program. Accessed April 3, 2017 http://www.fpo.go.th/FPO/modules/Content/getfile.php?contentfileID=3853

Gillings, D., D. Makuc, and E. Siegel. 1981. Analysis of interrupted time series mortality trends: an example to evaluate regionalized perinatal care. *American Journal of Public Health* 71: 38-46.

Haraguchi, M. and Lall, U., 2015. Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction*, *14*, pp.256-272.

Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D, Ballester F, Boumghar A, Anderson HR, Wojtyniak B, Paldy A, Braunstein R, Pekkanen J, Schindler C, Schwartz J Epidemiology. 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. *Sep;* 12(5):521-31.

Chuersuwan N, Nimrat S, Lekphet S, Kerdkumrai. 2008. Levels and major sources of PM2.5 and PM10 in Bangkok Metropolitan Region. *T Environ Int* 34(5): 671-7.

Levinson, A. 2012. Valuing public goods using happiness data: The case of air quality. *Journal of Public Economics* 96: 869-880.

Luttmer, Erzo F.P. 2005. Neighbors as negatives: relative earnings and well-being. *Quarterly Journal of Economics* 120 (3): 963–1002.

Muller, A. 2004. Florida's motorcycle helmet law repeal and fatality rates. *American Journal of Public Health* 94: 556-558.

Nerlove, Marc, David M. Grether, and Jose´ L. Carvalho. 1979. Analysis of economic time series. New York: Academic Press.

Noparumpa, T., and Saengchote, K. 2017. The impact of tax rebate on used car market: Evidence from Thailand. *International Review of Finance* 17: 147–154. doi: 10.1111/irfi.12094.

PCD (Pollution Control Department) 2010. Ministry of Natural Resources and Environment. Annual Air Quality [in Thai] Accessed April 3, 2017 http://aqnis.pcd.go.th

Pearson, T., Campbell, M.J. and Maheswaran, R. 2016. Acute effects of aircraft noise on cardiovascular admissions–an interrupted time-series analysis of a six-day closure of London Heathrow Airport caused by volcanic ash. *Spatial and Spatio-temporal Epidemiology* 18: 38-43.

Phetcharat, S., R. Buntan and S. Chintarat. 2015. Impact from the Government's first car policy on traffic volume and travel speed in Bangkok. *Journal of Science and Technology* 23(5): 854-866.

Powdthavee, Nattavudh. 2009. How much does money really matter? Estimating the causal effects of income on happiness. *Empirical Economics* 39 (1): 77–92.

Prais, S. J., and C. B. Winsten. 1954. Trend estimators and serial correlation. Working paper 383, Cowles Commission. http://cowles.econ.yale.edu/P/ccdp/st/s-0383.pdf

Wong CM, Vichit-Vadakan N, Kan H, Qian Z. 2008. Public health and air pollution in Asia (PAPA): a multicity study of short-term effects of air pollution on mortality. *Environ Health Perspect* 116(9):1195-202.

Ruchirawat, M., Settachan, D., Navasumrit, P., Tuntawiroon, J. and Autrup, H. 2007. Assessment of potential cancer risk in children exposed to urban air pollution in Bangkok, Thailand. *Toxicology letters*, *168*(3): 200-209.

Stallings-Smith, S., Zeka, A., Goodman, P., Kabir, Z. and Clancy, L. 2013. Reductions in cardiovascular, cerebrovascular, and respiratory mortality following the national Irish smoking ban: interrupted time-series analysis. *PloS one 8*(4): 62063.

Seinfeld, John H., and Spyros N. Pandis. 1998. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. New York: Wiley.

Welsch, H. 2002. Preferences over prosperity and pollution: environmental valuation based on happiness surveys. *Kyklos* 55: 473-494.

Welsch, H. 2006. Environment and happiness: valuation of air pollution using life satisfaction data. *Ecological Economics* 58: 801–813.

WHO. 2017. Accessed April 3, 2017
http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

WHO. 2016. Mortality due to air pollution, world health statistics. 2016 Accessed April 3, 2017 http://www.who.int/gho/publications/world_health_statistics/2016/whs2016_AnnexA_MortalityAirPollution.pdf?ua=1&ua=1

William R.. Shadish, Cook, T.D. and Campbell, D.T. 2002. Experimental and quasi-experimental designs for generalized causal inference. Wadsworth Cengage learning.

Yinon, L. and Thurston, G., 2017. An evaluation of the health benefits achieved at the time of an air quality intervention in three Israeli cities. *Environment International*.

Zellner, A. 1962. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association* 57: 348–368.

Zhang, B. Top 5 Most Expensive Natural Disasters in History. Accessed April 3, 2017 http://www.accuweather.com/en/weather-news/top-5-most-expensive-natural-d/47459

Zhang, X., Zhang, X. and Chen, X. 2017. Valuing Air Quality Using Happiness Data: The Case of China. *Ecological Economics* 137: 29-36.

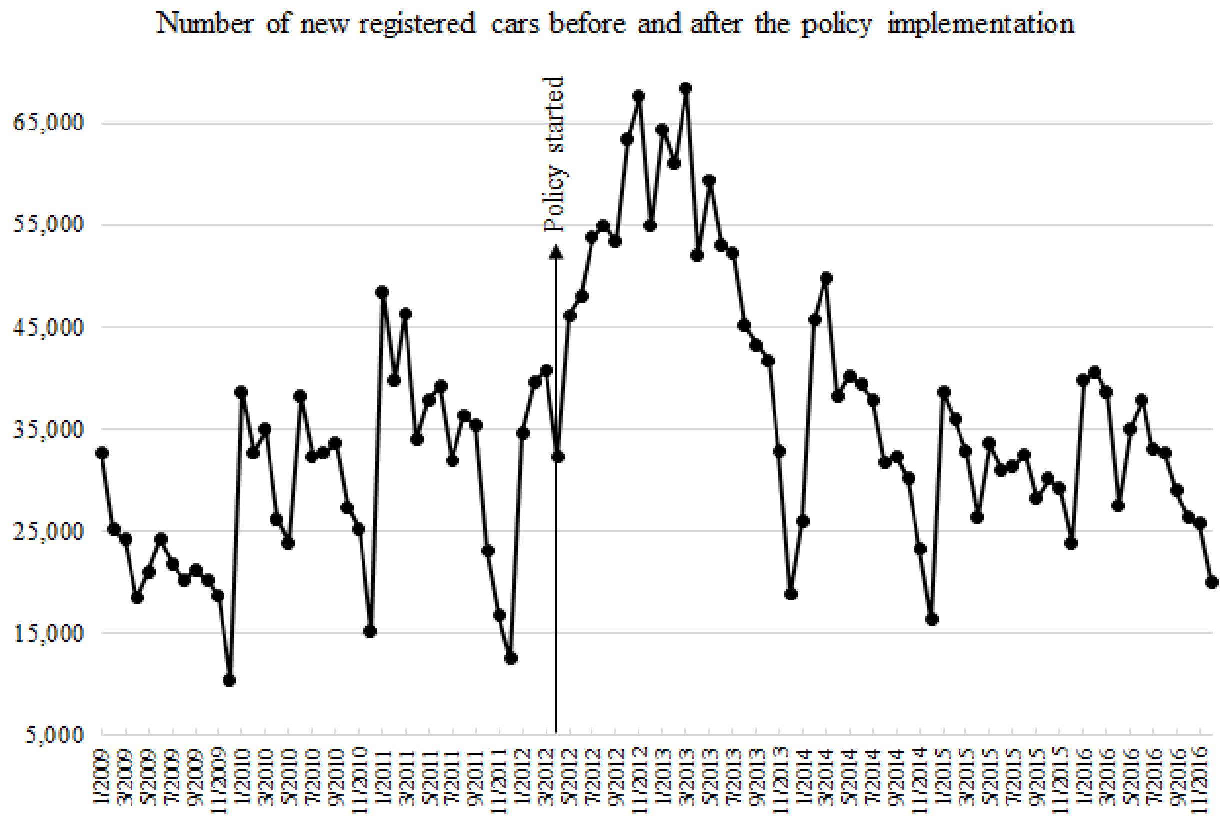

Figure 1. Number of monthly new registered cars before and after the program in Bangkok

Source: Department of Land Transport (2016)

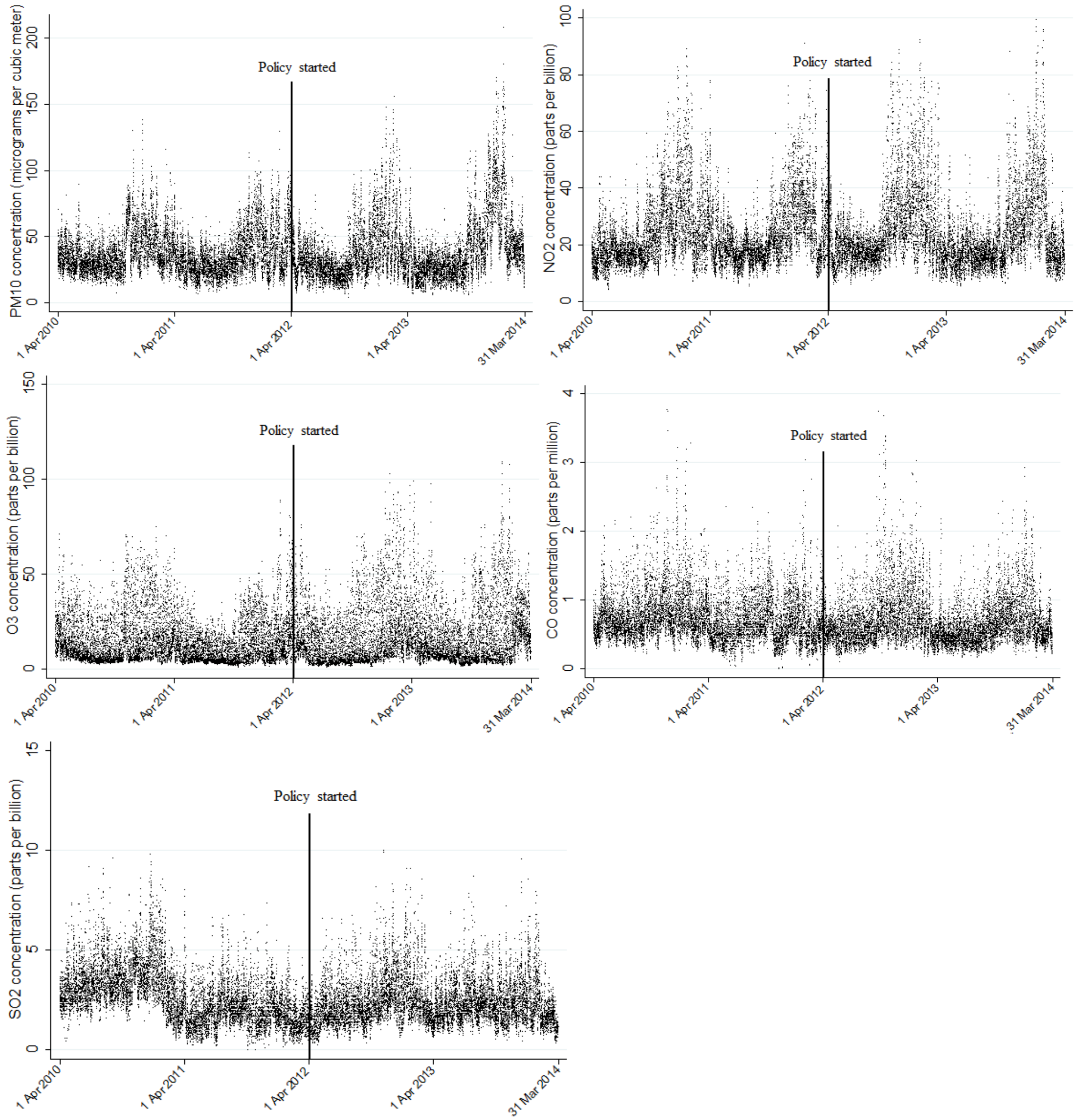

Figure 2. Air quality in Bangkok during 1 April 2010 - 31 March 2014

Source: Department of Pollution Control (2016)

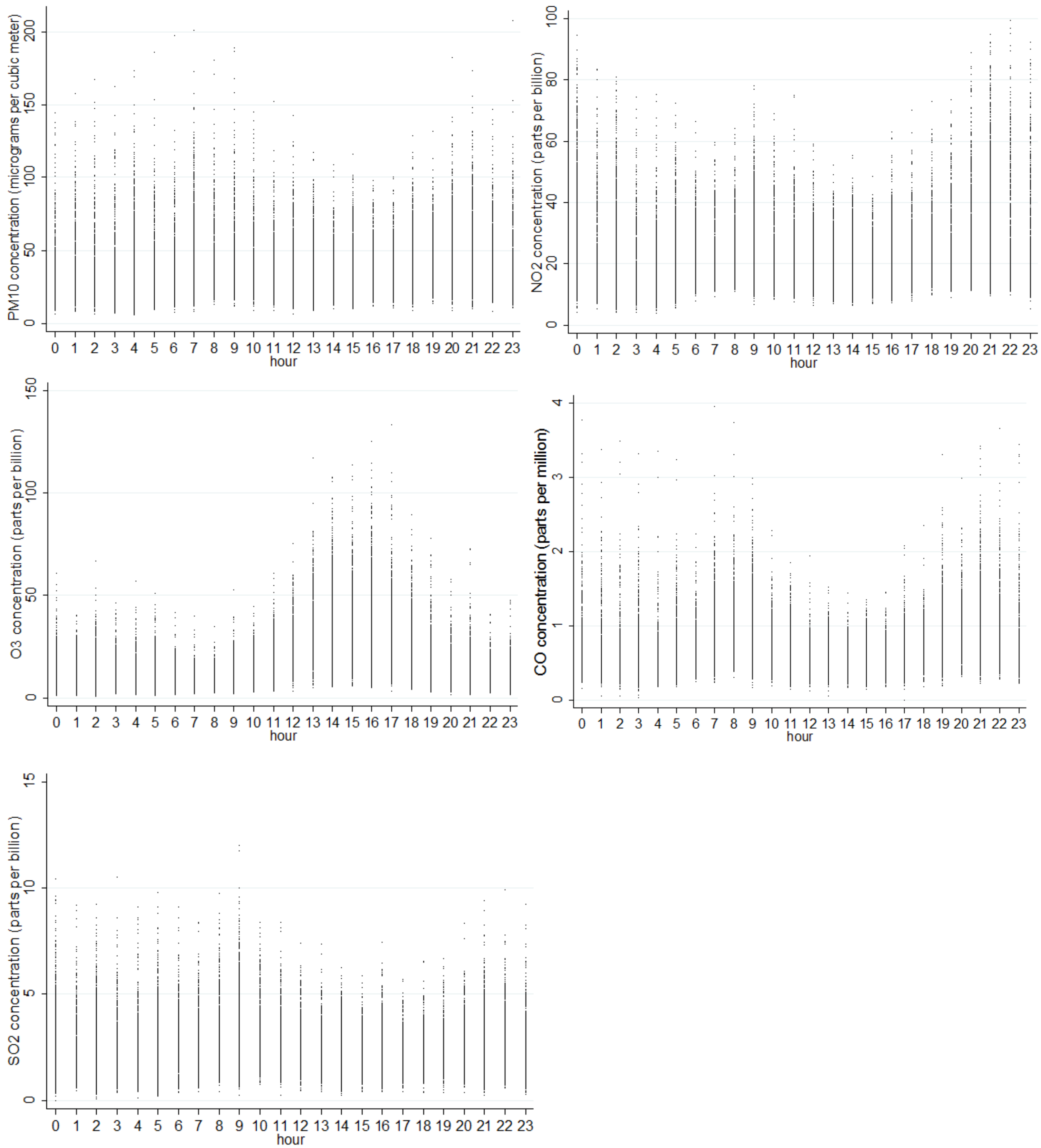

Figure 3. Daily pattern of air quality in Bangkok

Source: Department of Pollution Control (2016)

Table 1. Air quality in Bangkok during 1 April 2010 – 31 March 2015: Summary statistics

	All Periods		Before Program		After Program	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
PM_{10} (μg/m^3)	38.8508	20.3578	37.9601	16.5515	39.7427	23.5277
NO_2 (ppb)	24.1236	12.1365	23.8704	11.2564	24.3771	12.9534
O_2 (ppb)	16.4120	14.2661	14.6483	12.1130	18.1782	15.9427
CO (ppm)	0.7192	0.3571	0.7464	0.3501	0.6919	0.3619
SO_2 (ppb)	2.5327	1.2481	2.6695	1.3381	2.3956	1.1346
Temperature (°C)	29.0484	2.9515	29.2314	2.9201	28.8651	2.9714
Rainfall (mm)	0.1835	1.0231	0.1831	1.0031	0.1840	1.0427
Relative humidity (%)	69.3088	12.6831	69.2678	12.3367	69.3498	13.0209
Wind speed (m/s)	1.2203	0.2991	1.3030	0.2523	1.1374	0.3187
Observation	35,064		17,544		17,520	

Table 2. Summary statistics of variables used to estimate the willingness to pay

Variable	Mean	Std. Dev.
Life satisfaction	7.7206	1.3109
Household characteristics		
Male	0.4694	0.4991
Age 15-19	0.0684	0.2525
Age 20-29	0.1414	0.3484
Age 30-39	0.2072	0.4053
Age 40-49	0.2343	0.4235
Age 50-59	0.2072	0.4053
Age $\geq$ *60**	0.1416	0.3487
*Single**	0.1982	0.3986
Married	0.6950	0.4604
Divorce	0.1069	0.3089
Thai	0.9961	0.0623
Bachalor	0.1083	0.3108
Employed	0.1202	0.3252
Good health	0.6118	0.4873
Fair to bad health	0.3796	0.4853
Very bad health	0.0086	0.0922
No. household members	3.7263	1.6030
Municipal	0.3641	0.4812
Annual household income	4,679.1002	4,910.2405
Pollutants		
PM_{10} *(µg/m³)*	37.3926	10.7338
NO_2 *(ppb)*	12.9685	4.7932
O_3 *(ppb)*	20.2253	3.9496
CO (ppm)	0.6014	0.1872
SO_2 *(ppb)*	2.7502	2.7805
Weather conditions		
Temperature (°C)	26.8643	0.9425
Rainfall (mm.)	164.5005	66.9597
No. of Observation	54,100	

Table 3. Coefficients for each pollutant specification using the Prais–Winsten regression

Variable	(1) PM_{10}	(2) NO_2	(3) O_3	(4) CO	(5) SO_2
T	-0.000338**	1.05e-05	-0.000252***	-1.26e-05***	-0.000155***
	(0.000153)	(5.85e-05)	(5.17e-05)	(1.37e-06)	(5.32e-06)
First	-17.33***	7.101***	-1.644	0.0505	-1.179***
	(3.902)	(1.493)	(1.515)	(0.0358)	(0.132)
*First*T*	0.000976***	-0.000302***	0.000387***	3.15e-06*	0.000135***
	(0.000176)	(7.09e-05)	(7.26e-05)	(1.70e-06)	(6.53e-06)
Weekday	1.460	1.829***	-0.969***	0.0493*	0.367***
	(0.983)	(0.644)	(0.365)	(0.0257)	(0.0652)
Severeflood	-1.732	-5.330***	-0.880	-0.260***	-0.437***
	(3.735)	(1.264)	(1.071)	(0.0329)	(0.151)
Temperature	-0.897	-1.187*	-1.247**	-0.105***	0.0235
	(1.106)	(0.702)	(0.633)	(0.0190)	(0.0650)
Temp_sq	0.0356*	0.00884	0.0491***	0.00153***	-0.000786
	(0.0182)	(0.0115)	(0.0104)	(0.000315)	(0.00109)
Rainfall	-0.301***	-0.699***	0.571***	-0.0377***	-0.0854***
	(0.0803)	(0.0462)	(0.0410)	(0.00209)	(0.00606)
Rainfall_sq	0.0115**	0.0215***	-0.0166***	0.00128***	0.00350***
	(0.00471)	(0.00278)	(0.00289)	(0.000140)	(0.000396)
Relativehumid	2.105***	0.699***	-1.075***	0.00523*	0.0607***
	(0.254)	(0.175)	(0.196)	(0.00317)	(0.0179)
Humid_sq	-0.0118***	-0.00518***	0.00700***	1.66e-05	-0.000502***
	(0.00182)	(0.00126)	(0.00145)	(2.22e-05)	(0.000132)
Windspeed	-5.934***	-8.906***	6.015***	-0.156***	-0.326***
	(1.245)	(0.807)	(0.623)	(0.0290)	(0.0882)
Windsp_sq	1.535***	1.761***	-2.107***	0.0371***	0.0170
	(0.426)	(0.279)	(0.224)	(0.0103)	(0.0317)
Constant	-26.00*	47.67***	50.17***	2.471***	2.998***
	(14.53)	(9.014)	(6.247)	(0.284)	(0.784)
R-squared	0.127	0.186	0.521	0.257	0.122
Durbin-Watson	2.268	2.134	1.824	2.212	2.169

Note: ***, **, * are significant at the 1, 5, and 10 percent level, respectively. Standard errors are reported in parentheses. The models also include dummy variables for month of the year, hour of the day, as well as interactions between weekday and hour of the day and interactions between wind speed and wind direction.

Table 4. Average changes in concentration levels of pollutants after program implementation

Pollutant (unit)	Without the program	With the program	Change in concentration
PM_{10} (μg/m^3)	31.6337	39.9879	8.3542
	(0.0845)	(0.0968)	(0.0373)
NO_2 (ppb)	25.2266	24.3717	-0.8549
	(0.0623)	(0.0597)	(0.0116)
O_3 (ppb)	9.6200	18.1558	8.5358
	(0.0889)	(0.0903)	(0.0148)
CO (ppm)	0.5583	0.6917	0.1334
	(0.0017)	(0.0017)	(0.0001)
SO_2 (ppb)	0.0138	2.3969	2.3831
	(0.0065)	(0.0043)	(0.0052)

Note: Standard errors are reported in parentheses.

Table 5. Life satisfaction, pollution, and income: linear regression with the instrumental variable

VARIABLES	PM_{10}	NO_2	O_3	CO	SO_2
Log (income) [γ]	0.70014***	0.69443***	0.69004***	0.69578***	0.69609***
	(0.05515)	(0.05500)	(0.05464)	(0.05508)	(0.05508)
Pollutants [α]	-0.00277***	-0.00842***	-0.00420**	-0.35673***	-0.00650
	(0.00059)	(0.00178)	(0.00202)	(0.04149)	(0.00543)
Male	-0.05429***	-0.05331***	-0.05411***	-0.05327***	-0.05388***
	(0.01156)	(0.01155)	(0.01156)	(0.01155)	(0.01156)
Age 15-19	-0.28898***	-0.29077***	-0.28950***	-0.29345***	-0.28759***
	(0.03511)	(0.03511)	(0.03511)	(0.03507)	(0.03509)
Age 20-29	-0.42339***	-0.42461***	-0.42384***	-0.42706***	-0.42198***
	(0.02719)	(0.02719)	(0.02721)	(0.02719)	(0.02718)
Age 30-39	-0.41349***	-0.41308***	-0.41377***	-0.41581***	-0.41162***
	(0.02513)	(0.02513)	(0.02515)	(0.02511)	(0.02512)
Age 40-49	-0.35297***	-0.35216***	-0.35255***	-0.35468***	-0.35190***
	(0.02498)	(0.02496)	(0.02498)	(0.02496)	(0.02497)
Age 50-59	-0.18326***	-0.18295***	-0.18168***	-0.18411***	-0.18184***
	(0.02394)	(0.02394)	(0.02392)	(0.02391)	(0.02393)
Married	-0.04707**	-0.04712**	-0.04397**	-0.04689**	-0.04638**
	(0.01963)	(0.01962)	(0.01957)	(0.01961)	(0.01962)
Divorce	-0.14889***	-0.15059***	-0.15015***	-0.15055***	-0.15042***
	(0.02786)	(0.02783)	(0.02783)	(0.02784)	(0.02785)
Thai	0.30636***	0.31215***	0.30686***	0.31055***	0.30706***
	(0.10073)	(0.10051)	(0.09978)	(0.10043)	(0.10038)
Bachelor	-0.05173	-0.04720	-0.04496	-0.04695	-0.04887
	(0.04451)	(0.04438)	(0.04417)	(0.04446)	(0.04445)
Employed	0.05654**	0.05460**	0.05697**	0.05519**	0.05636**
	(0.02252)	(0.02247)	(0.02250)	(0.02250)	(0.02251)
Fair to bad health	-0.33857***	-0.33956***	-0.34162***	-0.34080***	-0.33983***
	(0.01526)	(0.01524)	(0.01516)	(0.01523)	(0.01524)
Very bad health	-0.65250***	-0.65509***	-0.64988***	-0.65203***	-0.65233***
	(0.08496)	(0.08482)	(0.08504)	(0.08502)	(0.08502)
No. household members	-0.01735***	-0.01711***	-0.01717***	-0.01755***	-0.01766***
	(0.00548)	(0.00546)	(0.00546)	(0.00548)	(0.00548)
Municipal	-0.14257***	-0.13946***	-0.13621***	-0.14308***	-0.14107***
	(0.01587)	(0.01581)	(0.01568)	(0.01585)	(0.01586)
Temperature (°C)	1.80790***	1.68544***	1.99905***	1.66247***	1.70652***
	(0.35761)	(0.35679)	(0.35688)	(0.35646)	(0.35747)
Rainfall (mm.)	0.00146***	0.00129**	0.00172***	0.00160***	0.00154***
	(0.00051)	(0.00052)	(0.00052)	(0.00051)	(0.00052)
Temp_sq	-0.03956***	-0.03722***	-0.04142***	-0.03702***	-0.03772***
	(0.00675)	(0.00674)	(0.00676)	(0.00673)	(0.00675)
Rain_sq	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
IV tests:					
Excluded instruments F stat	1104.99	1110.87	1118.25	1106.39	1106.89
P-val (Kleibergen-Paap rk LM)	0.000	0.000	0.000	0.000	0.000
P-val (Stock-Wright LM S)	0.000	0.000	0.000	0.000	0.000

Note: Constant term , regional dummies for Central, East, Northeast, South, and Bangkok and max temperature and max rainfall are included. ***, **, * are significant at the 1, 5, and 10 percent level, respectively. Standard errors are reported in parentheses.

Table 6. Estimated annual household willingness to pay for a unit reduction

VARIABLES	PM_{10}	NO_2	O_3	CO	SO_2
Linear regression with the instrumental variable					
Log (income) [γ]	0.70014***	0.69443***	0.69004***	0.69578***	0.69609***
	(0.05515)	(0.05500)	(0.05464)	(0.05508)	(0.05508)
Pollutants [α]	-0.00277***	-0.00842***	-0.00420**	-0.35673***	-0.00650
	(0.00059)	(0.00178)	(0.00202)	(0.04149)	(0.00543)
WTP for a unit reduction	65.789***	201.796***	101.312**	8,533.496***	155.471
	(14.822)	(42.437)	(48.002)	(1,214.243)	(129.988)
Ordered probit with the instrumental variable					
Log (income) [γ]	0.55987***	0.55576***	0.55522***	0.55630***	0.55424***
	(0.03997)	(0.03989)	(0.03945)	(0.03982)	(0.03988)
Pollutants [α]	-0.00220***	-0.00619***	-0.00332**	-0.28322***	-0.00487
	(0.00047)	(0.00143)	(0.00160)	(0.03275)	(0.00429)
WTP for a unit reduction	65.270***	185.476***	99.551**	8,473.748***	146.235
	(14.644)	(42.760)	(47.531)	(1,203.247)	(129.132)

Note: The unit of PM_{10} is $\mu g/m^3$, while the unit of NO_2, O_3, and SO_2 are ppm and the unit of CO is ppm. Other covariates and fixed effects as in the first column of table 5.

Table 7. Annual total environmental cost of air pollution from the first car buyer program

Pollutant (unit)	Change in concentration	WTP ($/unit)	Environmental cost ($/household/year)	Total environmental cost ($/year)
PM_{10} (mg/m^3)	8.3542 (0.0373)	65.789 (14.437)	549.614 (0.539)	1,425,604,836
NO_2 (ppb)	-0.8549 (0.0116)	201.796 (42.437)	-172.515 (0.492)	-447,475,103
O_3 (ppb)	8.5358 (0.0148)	101.312 (48.002)	864.779 (0.710)	2,243,087,040
CO (ppm)	0.1334 (0.0001)	8,533.496 (1,214.243)	1,138.368 (0.121)	2,952,730,605
			Total damage	6,173,947,377