

# **Income Elasticity of Willingness to Pay for Better Air Quality: Effect of Private Environmental Substitute**

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## **Abstract**

We use a nested CES utility function to introduce a private environmental substitute in a theoretical model. We found that buyer's income elasticity of WTP increases with price of the substitute and decreases with income. Meanwhile, a higher price and a lower income also discourage purchase of the substitute, reducing the proportion of buyers in population. We therefore need to consider both dimensions while discussing societal mean WTP. An empirical check based on a contingent valuation survey confirms our theoretical findings. The projected income-WTP curves reveal inequality reduces the mean WTP more in the presence of private environmental substitutes.

**Keywords:** income elasticity of willingness to pay, private environmental substitute, income inequality, income effect, substitution effect, air quality

## 1. Introduction

Non-market valuation methods occupy an important place in environmental cost-benefit analysis (CBA) (OECD, 2018). They are used extensively for environmental policy and investment decision-making because they provide a monetary measurement of variations in well-being that are brought about by projects or policies that deliberately aim to improve the environment.

A central step in environmental CBA is to aggregate the environmental and social benefits and costs across the population in a given geographical area. In principle, if a representative sample is drawn from the entire population living in a geographical area, then multiplying the sample's mean WTP by the population of the sampled area should give an accurate estimate of the aggregate values for the sampled area (Bateman et al. 2006). However, this aggregation technique, which focuses on the sample's mean WTP as determined from its mean income, may overlook the potential impact of income inequality on the incidence of non-market environmental good provision.

Frank and Schlenker (2016) proposed that if preservation values increase with income, but at a decreasing rate, then a more equal society will exhibit higher conservation values. Their conjecture is confirmed by Baumgärtner et al. (2017), whose theoretical development and simulations showed that if the constant income elasticity of WTP is less than one, societies with a more equal distribution of income have a higher mean WTP and therefore the possibility for more environmental good provision. Drupp et al. (2018) provided a

simple but intuitive graphical analysis relating mean WTP to income inequality in which they depict the less-than-one income elasticity of WTP as an increasing but concave income-WTP curve. In their illustration, a Pigou-Dalton transfer from a wealthier household to a poorer one that reduces income inequality but leaves society's mean income unchanged can lead to a higher WTP. This is because the increase of WTP of the poorer household after receiving the transfer is higher than the decrease in WTP of the wealthier household.

Empirical evidence from past studies employing the contingent valuation method (CVM) suggests that the income elasticity of WTP for environmental goods is mostly between 0.1 and 0.6 (Kristom and Riera, 1996; Söderqvist and Scharin, 2000; Hammitt et al., 2001; Barton, 2002; Ready et al., 2002; Horowitz & McConnell, 2003; Hörby & Söderqvist, 2003; Liu & Stern, 2008; Jacobson & Hanley, 2009; Khan, 2009; Broberg, 2010; Pek et al., 2010; Wang et al., 2013; Wang et al., 2014; Wang et al., 2020; He & Zhang, 2021, etc.). The less-than-one income elasticity of WTP signifies that the ratio of total benefits from environmental improvement to income increases more slowly than income does, so the benefits favor the poor in relative terms. Under such conditions, applying the aggregation rule that focuses on the sample's mean WTP and the total population of the sampled area will lead to a lower distribution of environmental goods, which affects the poor more than the rich.

Understanding the income elasticity of WTP is therefore important to be able to assess the distributional consequences of environmental policy. Several authors have studied this relationship in their theoretical models. Flores and Carson (1997) investigated the income elasticity of the virtual price for better environment. They found that while the income elasticity of the marginal value of WTP and the ordinary income elasticity of demand for better environment are related, the inverted cross-price demand substitution elasticities and the share of total consumption expenditures for the goods concerned also matter. Following up on previous works that contributed to deriving the measurement of the benefit of public goods (Aaron and McGuire, 1971; Kovenock and Sadka, 1981; Snow and Warren, 1983; Kristom and Riera, 1996; Flores and Carson, 1997), Ebert (2003) employed a general function form for consumer's utility which is strictly quasi-concave and increasing in both private consumption good and environmental good. By examining the utility maximization problem actually faced by a consumer and a pseudo-choice problem that included the environmental quality as part of an optimal solution, Ebert (2003) scrutinized the incidence of environmental benefits and showed that the income elasticity of marginal WTP is not only positively related to the income elasticity of demand for the environmental quality, but also negatively dependent on the weighted sum of the partial elasticity of substitution between each private good and the environmental quality. By supposing that all partial elasticities of substitution are the same, Ebert (2003) was able to come to the conclusion that the income elasticity of *marginal* WTP is equal to the ratio of the income elasticity of demand for the environmental quality over its elasticity of substitution with the private goods. Both studies cited here demonstrated that even when the environmental good is a demand luxury, i.e., its income elasticity of demand is greater than one, if its elasticity of

substitution with private goods is high enough, the income elasticity of *marginal* WTP can still be less than one.

Baumgartner et al. (2017) extended the work of Ebert (2003) by employing the constant elasticity of substitution (CES) utility function. This made it possible to directly relate the degree of substitutability/complementarity between environmental quality and a human-made private consumption good to WTP. One interesting implication of the CES function in Baumgartner et al. (2017) is that the income elasticity of WTP becomes simplified and equal to the inverse of the elasticity of substitution between the consumption good and the environmental quality. This means that the income elasticity of WTP is less than one if and only if the private good and the environmental quality are substitutes.

One thing these three studies have in common is that they all assume a simplistic duo-qualification of substitute/complement relationship between the environmental quality and the private consumption goods. However, in real life, different private goods may have heterogenous substitutability with the environmental quality. The literature of defensive expenditures provided several examples of such closer private environmental substitutes and the more recent studies started to report the direct causal effect between the variation of environmental quality and the modification in such defensive expenditure by directly observing households' behaviors. Deschênes et al. (2017) found the reduction in ambient ozone concentration in the US led to a reduction of 800 million dollars in pharmaceutical purchases. Zhang and Mu (2018) demonstrated that the consumption on anti-PM2.5 masks in Chinese cities increased by 70.6 percent with a 100-point increase in Air Quality Index

(AQI). Liu et al. (2018) also reported that increases in air pollution levels in Chinese cities were positively associated with higher online searches for anti-PM<sub>2.5</sub> masks and air purifier.

The existence of these closer private environmental substitutes may provide households with opportunity to adjust “quality of its personal environment” (Bartik, 1988) by choosing a level of defensive expenditure. Such “quality of personal environment” may in its turn alter households’ WTP for public environmental improvement project. In such circumstance, it becomes necessary to look into the potential defensive consumption in non-market valuation studies, especially when available private environmental substitutes are expensive. This is because wealthier household may be more inclined to adopt such defensive expenditure, which in turn bias the social mean WTP for public environmental improvement project downwards and leads to an even lower level of public good provision.

In this paper, we propose to extend the work of Baumgartner et al. (2017) by using a nested CES utility function whose top level is formulated as a CES relationship between the ordinary private goods bundle and the environmental goods bundle. The environmental goods bundle is characterized by another CES relationship, this time between a private environmental substitute and environmental quality, which are assumed to be closer substitutes than the aggregate private goods and environmental goods bundles.

By splitting the CES into two levels, we find the income elasticity of WTP of a non-buyer of a private environmental substitute to be the same as in Baumgartner et al. (2017), i.e.,

equal to the inverse of the elasticity of substitution between the ordinary consumption goods and environmental goods bundles. A buyer's income elasticity of WTP, on the other hand, is equal to the inverse of the product of the elasticity of substitution between the ordinary consumption goods and environmental goods bundles and the proportion of income that is used to consume ordinary private goods. This result echoes the conclusion of Flores and Carson (1997) and Ebert (2003). Based on this result, the income elasticity of WTP of a buyer of the private environmental substitute varies with their level of income and the price of the private environmental substitute. The lower their income is and the higher the price is, the higher the income elasticity of WTP of a buyer will be, compared to that of a non-buyer.

Our model also allows us to study people's decisions to purchase the private environmental substitute. Given the environmental conditions, we find that the probability a person will buy a private environmental substitute increases with their income and decreases with the price of the substitute.

Our model combining these two aspects shows that the discussion about the income elasticity of WTP and its impact on societal mean WTP for an economy, particularly an unequal one, requires us to consider two aspects simultaneously. On the one hand, the buyer's income elasticity of WTP increases with the price of the private environmental substitute and decreases with their income. But on the other hand, a higher price and a lower income also discourage an individual from buying the private environmental substitute, thereby reducing the proportion of buyers and the influence an increment in the

buyers' income elasticity of WTP has on the determination of mean WTP. We therefore need to take these two dimensions into consideration since they work in opposite directions.

The theoretical model's findings were confirmed by our empirical check based on CVM survey of people's WTP for a public policy aiming to reduce the air pollution and increase the number of "blue sky" days in Nanjing, China. First, our results reported the income elasticity of WTP for public policy was less than one (around 0.3), which is very close to the values reported in previous studies. Our analyses showed that the income elasticity of WTP of buyers of expensive air purifiers decreases significantly with their income, whereas that of buyers of masks does not. Our empirical check also reported that the probability of purchasing the private environmental substitutes (air purifiers and masks) depends closely on people's income level, although the magnitude of the statistically significant coefficient of income is larger for air purifier purchases than for mask purchases. We combined these two aspects of the results in an extrapolation exercise to obtain the simulated concave income-WTP relationship similar to Drupp et al. (2018). That exercise demonstrated that air purifier consumption leads to an important downward bending of the concave curvature, which signifies that a reduction in income inequality by a Pigou-Dalton transfer will result in a higher societal mean WTP, while mask consumption leads to only a marginal change in the income-WTP relationship.

This paper is organized as follows. We present our model in Section 2. Section 3 describes the survey, the data used and our identification strategy. Sections 4 to 6 present our empirical results. Section 7 contains a discussion and our conclusion.

## 2. Theoretical model

To guide our data analysis, in this section, we extend Baumgärtner et al.'s model (2017) to describe an individual consumer's utility  $U$  between a bundle of ordinary private goods  $X = X(x_1, x_2, \dots, x_m)$ , a private environmental substitute  $Y$  and the environmental quality  $Q$  as follows

$$U(X, E(Y, Q)) = \left( \alpha X^{\frac{\theta-1}{\theta}} + (1 - \alpha) E^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} \text{ and } E(Y, Q) = \left( \beta Y^{\frac{\omega-1}{\omega}} + (1 - \beta) Q^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}}. \quad (1)$$

The variable  $\theta$  is the CES between the ordinary private consumption goods bundle  $X$  and the environmental goods bundle  $E$ , and we assume  $\theta > 1$  to describe the substitution relationship between bundles  $X$  and  $E$ . Bundle  $E$  is further formulated as a nested second-level CES function between the private environmental substitute  $Y$  and the environmental quality  $Q$ , with the CES being  $\omega$ . We also assume  $Y$  and  $Q$  are closer substitutes than  $X$  and  $E$  are, so  $\omega > 1$  and  $\theta < \omega$ . The variable  $\alpha$  represents the weight of the ordinary private goods bundle  $X$ , and  $\beta$  is the weight of the environmental private good  $Y$  in the environmental goods bundle  $E$ . We assume  $0 < \alpha < 1$  and  $0 < \beta < 1$ . This nested CES function is the simplest utility function that we can use to capture the different degrees of substitution of  $Y$  and  $Q$  and their joint degree of substitution with respect to the ordinary private goods bundle  $X$ .

By scaling the price of  $X$  to be the numeraire, given an income  $M$  and the price of the private environmental substitute  $Y$ , which is represented by  $p$ , this consumer problem can be expressed as

$$\begin{aligned} & \max U(X, E(Y, Q)) \\ & s. t. \quad X + pY = M \text{ with } Q \text{ fixed.} \end{aligned} \quad (2)$$

We simplify this nested CES function by further assuming that given income  $M$ , price  $p$  and the environmental quality  $Q$ , the individual faces a non-marginal decision about whether or not to buy one unit of the environmental private substitute, so  $Y \in \{0,1\}$ . We believe this non-marginal consumption decision fits well with the two environmental private substitutes that we consider in this paper. First, since the air purifier is an expensive durable good for most families, the consumption decision to make regarding it is whether to buy or not buy it. For the mask, considering that its utility is directly dependent on the environmental conditions at the time of making a decision and that environmental conditions vary quickly from one day to the next, we can also consider the decision whether or not to wear a mask to be dependent on income  $M$ , the price of a mask,  $p$ , and the environmental quality  $Q$  at the time of making the decision. So, the utility function can be simplified as Eq. (3) when the individual decides to buy one unit of  $Y$ , so  $Y = 1$ , and as Eq. (4) when they decide not to buy it, so  $Y = 0$ .

$$U^{Y=1} = \left( \alpha(M - p)^{\frac{\theta-1}{\theta}} + (1 - \alpha) \left[ \beta + (1 - \beta)Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} \quad (3)$$

$$U^{Y=0} = \left( \alpha M^{\frac{\theta-1}{\theta}} + (1-\alpha) \left[ (1-\beta) Q \frac{\omega-1}{\omega} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}. \quad (4)$$

The individual decides to buy one unit of  $Y$  if and only if  $U^{Y=1} > U^{Y=0}$ . It follows from Eqs. (3) and (4) that this condition signifies that

$$\left[ \beta + (1-\beta) Q \frac{\omega-1}{\omega} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}} - \left[ (1-\beta) Q \frac{\omega-1}{\omega} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}} > \frac{\alpha}{1-\alpha} \left[ M^{\frac{\theta-1}{\theta}} - (M-p)^{\frac{\theta-1}{\theta}} \right] \quad (5)$$

The left-hand side of the inequality (5) is dependent only on the level of  $Q$ , while the right-hand side is dependent on both income  $M$  and price  $p$ . By assuming  $A =$

$$\frac{\alpha}{1-\alpha} \left[ M^{\frac{\theta-1}{\theta}} - (M-p)^{\frac{\theta-1}{\theta}} \right] \text{ and } B = \left[ \beta + (1-\beta) Q \frac{\omega-1}{\omega} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}} - \left[ (1-\beta) Q \frac{\omega-1}{\omega} \right]^{\frac{\omega}{\omega-1} \frac{\theta-1}{\theta}},$$

we obtain

$$\frac{\partial A}{\partial M} = \frac{\alpha}{1-\alpha} \frac{\theta-1}{\theta} \underbrace{\left[ M^{-\frac{1}{\theta}} - (M-p)^{-\frac{1}{\theta}} \right]}_{<0} < 0. \quad (6)$$

We know from Eq. (6) that  $A$ , or the right-hand side of the inequality (5), decreases with  $M$ . Therefore, a higher value of  $M$  increases the chance for the inequality (5) to hold, which signifies a higher probability of consuming one unit of  $Y$ . We therefore have the consumption of  $Y$  increasing with income  $M$ , which corresponds to the basic economic intuition that predicts the consumption of a normal good increases with income growth.

$$\frac{\partial A}{\partial p} = \frac{\alpha}{1-\alpha} \frac{\theta-1}{\theta} \underbrace{(M-p)^{-\frac{1}{\theta}}}_{>0} > 0 \quad (7)$$

Eq. (7) indicates that the right-hand side of the inequality (5) increases with  $p$ , the price of  $Y$ . So, the higher price  $p$  is, the smaller the chance is that the inequality (5) holds. This means the probability of consuming  $Y$  is lower when its price becomes higher, which also corresponds to our economic intuition.

$$\frac{\partial B}{\partial Q} = \frac{\theta-1}{\theta} (1-\beta) \underbrace{Q^{-\frac{1}{\omega}}}_{>0} \underbrace{\left\{ \left[ \beta + (1-\beta) Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}} - \left[ (1-\beta) Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}} \right\}}_{<0} < 0 \quad (8)$$

Finally, Eq. (8) reveals that the left-hand side of the inequality (5) decreases with  $Q$ . This means better environmental quality will reduce the chance for the inequality (5) to hold, so we should expect the probability of consuming  $Y$  to be lower when  $Q$  increases. This is also coherent with our economic intuition.

To derive the WTP for the environmental quality  $Q$ , we need to write the consumer problem in such a way that we treat the environmental quality as a pseudo market good, i.e., they can buy  $Q$  at a price  $\varphi$  and the amount of their total income then becomes  $\widehat{M}$ .

$$\begin{aligned} & \text{Max } U(X, E(Y, Q)) \\ \text{s. t. } & X + pY + \varphi Q = \widehat{M}. \end{aligned} \quad (9)$$

Therefore,  $\varphi$  (the implicit price of  $Q$ ), can be derived separately for those who buy the private environmental substitute and those who do not from their respective first-order conditions.

The Lagrangian of the consumer problem is

$$L = \left\{ \alpha X^{\frac{\theta-1}{\theta}} + (1-\alpha) \left[ \left( \beta Y^{\frac{\omega-1}{\omega}} + (1-\beta) Q^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}} \right]^{\frac{\theta-1}{\theta}} \right\}^{\frac{\theta}{\theta-1}} + \lambda (\widehat{M} - X - pY - \varphi Q) \quad (10)$$

The first-order conditions for  $X$  and  $Q$  are

$$\frac{\partial L}{\partial X} = \left\{ \alpha X^{\frac{\theta-1}{\theta}} + (1-\alpha) \left[ \left( \beta Y^{\frac{\omega-1}{\omega}} + (1-\beta) Q^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}} \right]^{\frac{\theta-1}{\theta}} \right\}^{\frac{1}{\theta-1}} \alpha X^{-\frac{1}{\theta}} - \lambda = 0 \quad (11)$$

$$\begin{aligned} \frac{\partial L}{\partial Q} = & \left\{ \alpha X^{\frac{\theta-1}{\theta}} + (1-\alpha) \left[ \left( \beta Y^{\frac{\omega-1}{\omega}} + (1-\beta) Q^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}} \right]^{\frac{\theta-1}{\theta}} \right\}^{\frac{1}{\theta-1}} (1-\alpha) \left( \beta Y^{\frac{\omega-1}{\omega}} + \right. \\ & \left. (1-\beta) Q^{\frac{\omega-1}{\omega}} \right)^{\frac{\theta-\omega}{(\omega-1)\theta}} (1-\beta) Q^{-\frac{1}{\omega}} - \lambda \varphi = 0. \end{aligned} \quad (12)$$

From Eqs. (11) and (12), we obtain

$$\varphi = \frac{(1-\alpha)(1-\beta) Q^{-\frac{1}{\omega}} \left[ \beta Y^{\frac{\omega-1}{\omega}} + (1-\beta) Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}}}{\alpha X^{-\frac{1}{\theta}}}. \quad (13)$$

Based on Baumgartner et al. (2017), WTP for a given environmental quality improvement  $\Delta Q$  can be written as

$$WTP = \varphi \Delta Q = \frac{(1-\alpha)(1-\beta)Q^{-\frac{1}{\omega}} \Delta Q \left[ \beta Y^{\frac{\omega-1}{\omega}} + (1-\beta)Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}}}{\alpha X^{-\frac{1}{\theta}}} \quad (14)$$

For a private environmental substitute non-buyer ( $Y = 0$ ), we have

$$WTP_{non-buyer} = \varphi_{Y=0} \Delta Q = \frac{(1-\alpha)(1-\beta)Q^{-\frac{1}{\omega}} \Delta Q \left[ (1-\beta)Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}}}{\alpha X^{-\frac{1}{\theta}}}. \quad (15)$$

As  $X=M$ , this non-buyer's income elasticity of WTP can be written as

$$\eta_{WTP, M, non-buyer} = \frac{\partial WTP}{\partial M} / \frac{WTP}{M} = \frac{1}{\theta}. \quad (16)$$

Therefore a private environmental substitute non-buyer's income elasticity of WTP for a better environmental quality expressed in Eq. (16) is the same as Eq. (4) in Baumgartner et al. (2017). More specifically, their income elasticity of WTP is equal to  $\frac{1}{\theta}$ . Since we assume that the environmental and private goods bundles are substitutes,  $\theta > 1$ , so the income elasticity of WTP is expected to be constant and less than one independent of other factors.

For a private environmental substitute buy ( $Y=1$ ), from eq. (14), we have

$$WTP_{buyer} = \varphi_{Y=1} \Delta Q = \frac{(1-\alpha)(1-\beta)Q^{-\frac{1}{\omega}} \Delta Q \left[ \beta + (1-\beta)Q^{\frac{\omega-1}{\omega}} \right]^{\frac{\theta-\omega}{(\omega-1)\theta}}}{\alpha X^{-\frac{1}{\theta}}} \quad (17)$$

As  $X = M - p$ , his/her income elasticity of WTP can be written accordingly as<sup>i</sup>

$$\eta_{WTP,M,buyer} = \frac{\partial WTP}{\partial M} \bigg/ \frac{WTP}{M} = \frac{1}{\theta \left(\frac{M-p}{M}\right)} = \frac{1}{\theta \left(1 - \frac{p}{M}\right)}. \quad (18)$$

Eq. (18) reveals that a private environmental substitute buyer's income elasticity of WTP is equal to the inversed product of  $\theta$  and the ratio of their expenditure on conventional private goods to their total income  $\left(1 - \frac{p}{M}\right)$ . This result in turn corresponds with the findings of Flores and Carson (1997) and Ebert (2003), which revealed that the income elasticity of WTP depends on the partial elasticity of substitution between the private and environmental goods bundles weighted by the share of total consumption expenditures that are for the conventional private goods. With  $p > 0$ , we have  $\left(1 - \frac{p}{M}\right) \leq 1$ , which means that those who bought the private environmental substitute should have a higher income elasticity of WTP than those who didn't.

We know from Eqs. (16) and (18) that, the difference between the income elasticity of WTP of a buyer and that of a non-buyer depends on two factors. The first is income,  $M$ . For a given value of  $p$ , the income elasticity of WTP of a buyer decreases with  $M$  and gradually converges to the same value as the income elasticity of WTP of non-buyers,  $\frac{1}{\theta}$ . The second factor is the price of the environmental private substitute,  $p$ . For a given value of  $M$ , an increase in  $p$  leads  $\left(1 - \frac{p}{M}\right)$  to decrease, which tends to enlarge the difference between the income elasticity of WTP of buyers and that of non-buyers, all else being equal.

In summary, our model shows two aspects must be considered when discussing the evolution of the income elasticity of WTP with respect to income,  $M$ , and the price of a private environmental substitute,  $p$ . The first aspect concerns the divergence of the income elasticity of WTP of buyers and that of non-buyers, and the second relates to an individual's decision to buy or not buy a private environmental substitute (c.f. the discussion on the inequality (5)).

More specifically, Eqs. (16) and (18) demonstrate that the income elasticity of WTP for a better environmental quality depends on the price of its close private substitute. The higher the price is, the larger its impact should be expected to be on the income elasticity of WTP of a person who bought the close private substitute, as compared to that of a non-buyer. At the same time, we know from the inequality (5) that the probability of buying a private environmental substitute decreases with its price. We therefore need to take these two dimensions into consideration since they work in opposite directions.

Similarly, for the relationship between income level and the income elasticity of WTP, on one hand, we know from Eqs. (16) and (18) that the higher the income level is, the smaller the proportion of income spent on the environmental substitute will be, which can in turn dilute the influence of environmental private substitute consumption on the income elasticity of WTP. On the other hand, however, we also know from the inequality (5) that an increase in income increases the probability of buying the private environmental substitute. Once again, these two aspects work in opposite directions.

### 3. Survey and data

Our CV survey was conducted as part of a larger survey of Nanjing residents' perceptions of the relationship between Nanjing's air quality and their health status. The data used in this paper came from the second edition of the survey, whose questions were mainly the same as those in the first edition of the survey, which took place between July 2014 and June 2015 (He et Zhang, 2021). The questionnaire that was used in both the first and second editions was developed from February 2014 to April 2014 with input from discussions with all project team members. A two-round pilot survey was conducted in May 2014, before the official launch of the project. More than 780 questionnaires were returned, and the suggestions and comments received were used to refine the final version of the questionnaire.

The second edition of the survey was conducted in Nanjing every second weekend from July 2015 to March 2016, in a total of 16 waves. For both the first and second editions of the survey, trained undergraduate students from Nanjing University randomly intercepted pedestrians on the street in all five districts of Nanjing and interviewed them in accordance with a structured questionnaire. The same sampling locations were used throughout the entire study period. For the second edition, 200 questionnaires were distributed each wave of the survey. A total of 1,951 respondents were recruited over the whole period. Our data constitutes a pseudo panel with identification of the location and wave fixed effects.

The final version of the survey was composed of seven sections and included questions about respondents' self-evaluated happiness level, health status, living conditions, air pollution-related risk awareness, regular activities, WTP for the air quality improvement project, and basic personal information. Respondents were assured of the anonymity of the survey at the beginning of each interview.

Prior to the WTP question, respondents were informed that the Nanjing municipal government was planning to launch a new comprehensive air quality improvement project that would significantly improve the air quality in Nanjing in two years and increase the number of "blue sky" days to over 80%. However, according to estimates, the project could not be implemented without collecting funds from households. The government was considering collecting an annual fee from households via their water bill, with fee collection managed by a relevant independent agency. The funds collected would be used only for the new comprehensive air quality improvement project, and information about the use of the funds would be made available to residents. Respondents were then asked to imagine that Nanjing residents had been given an opportunity to vote on implementing such an air quality improvement project. If a majority of people supported it, the project would be implemented and every household would need to pay the fee to improve air quality. If the majority of people voted against the project, it would not be implemented and residents would not need to pay the fee, but air quality would remain at the current level or further deteriorate. After being reminded of their budget constraints, respondents were asked to consider whether to accept or refuse an annual fee, randomly drawn from the following cost vector {10, 20, 30, 50, 100, 200, 500, 1000, 2000, 5000, 10000 Yuan}.<sup>ii</sup>

[insert Table 1 about here]

Table 1 provides descriptive statistics of the main variables used in our paper. We ended up with a total of 1,671 usable observations. Compared to the general population of Nanjing city, our samples contain relatively young and highly educated respondents whose mean age is around 27 years old. About 46% of respondents accepted the public air quality improvement project. As for the main variables, we observe about 10% of respondents had purchased masks and 13-15% of respondents had installed air purifiers in their home in the previous two years.

We conducted the empirical verification of our theoretical model in three steps in accordance with the context of our CV survey. First, since our data made it possible to directly distinguish buyers from non-buyers, we conducted estimates to compare the difference in the income elasticity of WTP of these two groups of respondents and to determine how such difference can be attributed to  $p$  and  $M$ . Second, we studied how respondents arrived at their decision to purchase the private environmental substitutes, with the aim of validating the role our theoretical model predicted for  $M$  in such decisions. Finally, the results obtained from these two steps were combined in a simulation exercise to obtain a similar illustration as the one provided in Drupp et al. (2018). By doing so, we hope to demonstrate how the responsiveness of the income elasticity of WTP with regard to  $p$  and  $M$  can further modify the distribution of mean WTP within a population.

#### **4. Income elasticity of WTP**

If we believe that environmental goods and consumption goods are substitutes and that the elasticity of substitution within the environmental goods bundle is greater than that between the private consumption goods and environmental goods bundles, so  $\omega > \theta$ , we can make the following three assumptions about the income elasticity of WTP.

- 1) The respondents who purchased a private environmental substitute should have a higher income elasticity of WTP than those who did not, all else being equal.
- 2) The income elasticity of WTP should change more significantly for a more expensive private environmental substitute (e.g., the air purifier) than for a cheaper one (e.g., the mask).
- 3) The income elasticity of WTP should increase more for relatively poorer respondents than for richer ones.

To test these three assumptions, we start with a simple determination function of the latent WTP of individual  $i$  as follows:

$$\ln WTP_i = \delta \ln income_i + Z_i' \rho + u_i + \varepsilon_i. \quad (19)$$

Here,  $\ln WTP_i$  is explained by  $\ln income_i$  and other relevant sociodemographic characteristics  $Z_i'$ , the residual  $u_i = \epsilon_w + \epsilon_d$ , is composed of wave ( $w$ ) and district ( $d$ ) fixed effects. The residual  $\varepsilon_i$  is unobserved to the econometrician but known to individual  $i$  since they know their  $WTP_i$ . Since both latent WTP and household income are in logarithm, the parameter to be estimated,  $\delta$ , can be directly interpreted as the income elasticity of WTP.

We are interested in running this WTP determination function to test whether  $\delta$ , the income elasticity of WTP, is less than or greater than 1.

To test the three assumptions listed above, we then add to Eq. (19) the cross-terms of  $f(\ln(\text{income}_i))$  with the dummy variables identifying whether respondents had bought the two private environmental substitutes (air purifiers and masks) in the previous two years. <sup>iii</sup>

$$\ln WTP_i = \delta \ln \text{income}_i + \sum_{s=1,2} [\gamma_s f(\ln \text{income}_i) \times \text{substitute}_{i,s}] + X_i' \rho + u_i + \varepsilon_i \quad (20)$$

From Eq. (20), we can derive the income elasticity of WTP as follow

$$\eta_{WTP, \text{income}} = \frac{\partial \ln WTP}{\partial \ln (\text{income})} = \delta + \sum_{s=1,2} \gamma_s \text{substitute}_{i,s} f'_{\ln(\text{income})}$$

To validate our first assumption concerning private environmental substitute buyers having a higher income elasticity of WTP than non-buyers, we should expect the coefficient  $\gamma_s$  to be statistically significant and

$$\sum_s \gamma_s \text{substitute}_{i,s} f'_{\ln(\text{income})} > 0 \text{ for } 1 = \text{air purifier}, 2 = \text{mask}.$$

For the second assumption, concerning the price of private environmental substitutes, we directly compare the estimates of the cross-terms with the air purifier dummy to that with the mask dummy. The reason that we include only dummy variables instead of detailed prices in Eq. (20) is that the survey respondents did not systematically report the price of the private environmental substitutes that they bought. Furthermore, we had difficulty

verifying the validity of the information provided by those who did report prices. But we believe focusing on the dummy variables identifying respondents' decisions to purchase these two substitutes should be sufficient, because for these two substitutes in particular, the general belief is that masks are very cheap and air purifiers are much more expensive, so the comparison of the magnitude and significance of the estimates obtained for their respective cross-terms should be able to reveal the general tendency related to the second assumption. If the assumption holds, we should obtain

$$\sum_1 \gamma_1 \text{substitute}_{i,1} f'_{\ln(\text{income})} > \sum_2 \gamma_2 \text{substitute}_{i,2} f'_{\ln(\text{income})}.$$

For each respondent, the comparison between air purifiers and masks comes down to the magnitude and statistical significance of the difference between  $\gamma_1$  and  $\gamma_2$ .

The cross-terms  $\gamma_s f(\ln \text{income}_i) \times \text{substitute}_{i,s}$  are also key for our third assumption, that the variation in the income elasticity of people's WTP following the purchase of a private environmental substitute is dependent on their income level. To test this assumption, we need to expect a non-linear function for  $f(\ln(\text{income}_i))$ .

In our survey, WTP is elicited from a referendum dichotomous choice question: when having to make a decision about the air quality improvement project, individual  $i$  either chooses to accept (Yes,  $C_i = 1$ ) or refuse (No,  $C_i = 0$ ) the proposed project at a given fee amount  $B_i$ . This decision is supposed to be dependent on the value of their latent  $\ln WTP_i$ , whose determination function is discussed in Eqs. (19) and (20). By assuming that

$\varepsilon_i \sim N(0, \sigma)$ , which follows a normal distribution with a zero mean and a variance of  $\sigma > 0$ , we adopt the maximum likelihood procedure proposed by Cameroun and James (1987), which can be written as follows, with  $\widehat{\ln WTP}_i$  signifying the deterministic part of the previous  $\ln WTP_i$  determination functions as eqs (22) and (23).

$$\ln L = \sum_i \left\{ (1 - C_i) \Phi \left[ \frac{\ln B_i - [\widehat{\ln WTP}_i]}{\sigma} \right] + C_i \left[ 1 - \Phi \left[ \frac{\ln B_i - [\widehat{\ln WTP}_i]}{\sigma} \right] \right] \right\} \quad (21)$$

This procedure exploits the variation in answers to the WTP question in discrete values ( $Y_i = 1/0$ ) and allows us to directly obtain separate point estimates of the regression-like slope coefficients for the deterministic part of the  $\ln WTP_i$  function. In these estimates, we focus mainly on the variables related to  $\ln income_i$ , i.e.  $\delta$  and  $\gamma_j$ , with  $j = \text{mask, air purifier}$ .

The first column of Table 2 reports the estimation results based on the WTP estimation function defined in Eq. (19). Models 2 to 7 are based on Eq. (20) with two different function forms for  $f(\ln income_i)$ .

[insert Table 2 about here]

First of all, our results confirm the general findings in the literature that people's WTP for better environmental quality is less than one. In our study, the income elasticity of WTP is estimated to be around 0.3, which is very close to the values reported in past studies. Based on our model, we can consider this result to confirm the substitution relationship between the environmental goods bundle and the ordinary private consumption goods bundle. When the income elasticity of WTP is less than one, WTP increases more slowly than income

does, which confirms that the distributional incidence of environmental benefit is regressive.

To test the three assumptions proposed in our study, we adopted various function forms for  $f(\ln income_i)$ . Table 2 first reports the results of a spline function for  $f(\ln(income_i))$ , in which the income range covered by our data is sectioned into four intervals – [0-4,000], (4,000-8,000], (8,000-25,000] and (25,000- $\infty$ ) – and each interval is captured by one income variable whose value is its true value if that value is within the interval and zero otherwise. The results reported for Models 2, 3 and 4 confirm that including the cross-terms with the dummy variables identifying respondents who had purchased the private environmental substitutes and  $f(\ln(income_i))$  significantly improves the model specifications, but only for the decision to purchase air purifiers (c.f. Models 2 and 3). Three of the four coefficients for the cross-term between income and the air purifier dummy reveal that, all else being equal, the respondents who had installed an air purifier at home had a significantly higher income elasticity of WTP than those who hadn't. Meanwhile, for the cross-term with the mask dummy, none of the four coefficients is statistically significant, meaning that there is no difference in the income elasticity of WTP between those who bought a mask and those who didn't. This can be explained by the fact that, in general, mask consumption should account for only a very small proportion of income, so  $(1 - \frac{p}{M})$  is very close to one. The situation with the air purifier is different, as it is an expensive durable good so  $(1 - \frac{p}{M})$  should be significantly less than one for its buyers. We consider these results to confirm our first and second assumptions.

This spline function was adopted to avoid the need for all four income interval variables to have the same coefficient and to approximate a curve for  $f(\cdot)$  in order to explore the validity of our third assumption.<sup>iv</sup> By comparing the coefficients obtained for the cross-terms between different income interval variables and the air purifier dummy, we can see that they decrease from 0.281 for income below 4,000 Yuan/month to 0.167 for the income interval 4,001-8,000 Yuan/month and then to 0.0974 for the income interval 8,001-25,000 Yuan/month, and finally close to zero (-0.0581 but not significant) for the income interval over 25,000 Yuan/month. The pattern of the results confirms our third assumption that the increase in income elasticity of WTP after purchasing a private environmental substitute becomes smaller with income. Our results confirm this dynamic for the decision to purchase an air purifier, not the decision to purchase a mask, which should, once more, be explained by the difference in their prices.

Based on the finding of Models 2, 3 and 4, we adopted a quadratic function form for  $f(\ln(\text{income}_i))$  in Models 5, 6 and 7, in which the private environmental good dummies are multiplied by the level and the square terms of  $\ln(\text{income})$ . Based on this function form, the income elasticity of WTP can be written as

$$\eta_{WTP, \text{income}} = \alpha + \sum_{s=1,2} [\gamma_{s, \text{level}} + 2\gamma_{s, \text{square}} \ln(\text{income})] \text{substitute}_{i,s}.$$

The results confirm once more our third assumption. For the two cross-terms with air purifier dummy, we have  $\widehat{\gamma_{s, \text{level}}} > 0$  and  $\widehat{\gamma_{s, \text{square}}} < 0$ , indicating the income elasticity of WTP decline gradually with  $\ln(\text{income})$ . But once more, this dynamic is confirmed only

for the decision to purchase an air purifier, not for the decision to purchase a mask, whose coefficients of the cross-term are insignificantly different from zero.

In addition to the main variables related to the purchase of the private environmental substitutes, our estimates also reveal several other sociodemographic variables, including gender and age, are significant determinants of WTP. An older male respondent had a significantly lower WTP for the public project than other respondents did. We did not find other socio-demographical characteristics, such as marital status, education level and health status, to have a significant role.

At the bottom of Table 2, we report the estimated mean WTP at around 190 Yuan (28.44 USD) per year for a representative respondent of our sample. we also find that for a same representative respondent, having installed air purifier at home or not can bring a very big impact on their WTP. All else being equal, a representative respondent with air purifier at home has mean WTP between 699-821Yuan (104-123 USD) per year while the same representative respondent having no air purifier at home only has a WTP between 150-174 Yuan (22-26 USD) per year. The mean WTP of the same representative respondent who bought mask during last two years is around 237-388 Yuan (35-58 USD) per year, signifying a much smaller gap with respect to the WTP of mask non-buyers.

## **5. Decision to purchase the private environmental substitute**

As a second step, we study our respondents' decision to buy or not buy a private environmental substitute. This question can be related to our discussion around the inequality (5) and the factors affecting the probability that an individual buys the private environmental substitutes, including income,  $M$ , environmental quality,  $Q$  and the price of the private substitute in question,  $p$ . In the context of our CV study, the current environmental quality  $Q$  and the price of the private substitute  $p$  can be considered exogenously provided. We therefore focus our attention on the relationship between people's decision to buy or not buy a private environmental substitute and their income level.

We first report in Figure 1, based on the raw data, the percentage of respondents in the different income groups that declared having purchased an air purifier/mask in the previous two years. Except for those with a monthly income of less than 500 Yuan, Figure 1 reveals the proportion of respondents who had installed an air purifier obviously increases with monthly income, from around 7-8% for those whose income is less than 5,000 Yuan per month to over 40% among those whose monthly income is over 50,000 Yuan. No similar trend is found for mask purchases.

[insert Figure 1 about here]

In Table 3, we reported students' tests on the mean income difference between those who bought private environmental substitutes in the previous two years and those who did not. These tests also confirm the difference in income is significant for the buyers of each substitute, but the mean income difference is much larger for air purifier buyers (5,739 Yuan) than for mask buyers (2,580 Yuan).

[insert Table 3 about here]

We estimated the relationship between income level and the decision to buy a private environmental substitute based on a Probit model (c.f. Table 4). The results of this Probit model confirmed the relationship between  $\ln(\text{income})$  and purchase decision is positive as expected, i.e., a higher income increases the probability for an individual to buy the private goods discussed in our paper. But the coefficient of  $\ln(\text{income})$  obtained for air purifier consumption is larger and more significant, which reveals the link between income and the decision to purchase an air purifier is stronger than the link between income and the decision to purchase a mask.

[insert Table 4 about here]

## **6. Impact of inequality on societal mean WTP**

The results that we presented in the last two sections clearly confirm the three assumptions made above about the income elasticity of WTP and the influence income level has on the probability of buying private environmental substitutes. In this section, the last question that we want to address is how the responsiveness of the income elasticity of WTP with regard to  $p$  and  $M$  can further modify the distribution of mean WTP within a population.

To answer this question, first of all, we illustrate how people's WTP evolves with income based on their decision to purchase the two private environmental substitutes considered. We do this by predicting people's WTP based on Models 2-7 from Table 2 and plotting the values obtained in diagrams of WTP versus monthly income. The fitted relationships

between predicted WTP and income are illustrated for both those who bought the substitutes and those who did not. We find in the four panels on the left-hand side of Figure 2 that the WTP of respondents who did not buy an air purifier increases slowly with income, which is generally expected in CV studies. However, the WTP of those who bought an air purifier in fact decreases with income. We also find that air purifier buyers' WTP decreases faster than air purifier non-buyers' WTP increases, and the two lines cross at an income level around 30,000 Yuan/month. Below this level, air purifier buyers have a higher WTP than non-buyers do at the same income level; beyond this level, non-buyers seem to have a higher WTP, although the difference is insignificant since the 95% CIs of the predicted WTP curves of buyers and non-buyers overlap.

[insert Figure 2 about here]

The four panels on the right-hand side of Figure 2 compare the evolution of WTP with income for both those who purchased a mask and those who did not. While we find WTP increases with income for mask non-buyers like it does for air purifier non-buyers, the WTP of those who bought a mask does not evolve in such a way as to demonstrate a clear tendency with income. Over the income range covered by our samples, it seems that those who bought a mask have a higher WTP than those who didn't, but this pattern is less significant for the richest respondents in Models 2 and 5, in which respondents' air purifier purchase decision is considered alongside their mask purchase decision.

While Figure 2 demonstrates the importance of considering the evolution of WTP with income for private environmental substitute buyers and non-buyers separately, the different

panels in the figure do not provide a definitive illustration of how societal mean WTP varies with the income elasticity of WTP and the probability of private environmental substitute consumption.

To illustrate this, we need to consider both the results from Section 4 on the relationship between income and individual WTP and those reported in Section 5 about how the probability to buy a private environmental substitute varies with income. We use the profile of a representative respondent chosen from our samples and the results reported in Sections 4 and 5 to illustrate this logic, and we simulate the relationship between mean WTP and monthly household income. The results are presented in Figure 3 and Figure 4.

[insert Figure 3 and Figure 4 about here]

For reference, for each of the panels presented in Figure 3 and Figure 4, we first simulated mean WTP based on the constant income elasticity of WTP that was obtained when estimating Model 1 of Table 2 by letting the representative respondent's household income be any value in the income range covered by our data, i.e., from 500 Yuan to 50,000 Yuan per month (c.f. the curves named WTP1 in each panel). The WTP1 curve shows that when we simply assume income elasticity is constant at 0.296 (c.f. Model 1 in Table 2), WTP for better air quality has a concave but increasing relationship with income. As for the impact of income inequality, Drupp et al. (2018) demonstrate in a similar, albeit theoretical, figure that a reduction in income inequality by a Pigou-Dalton transfer, i.e., a reduction in income inequality that leaves society's mean income unchanged, will result in an increase in societal mean WTP since the richer households' WTP decreases less than the poorer households' WTP increases.

In order to incorporate the impact of buying an air purifier on said representative respondent's WTP, we extrapolated to simulate the WTP\_buyer curve for a private substitute buyer using the income elasticity  $\delta + \gamma_{air\ purifier} f'(\ln(income))$  and the WTP\_non\_buyer curve using simply  $\delta$ .

These two WTP curves (WTP\_buyer and WTP\_non\_buyer) were then weighted by their corresponding share in the population to obtain for each income level the weighted average WTP (c.f. WTP\_weighted average). The share that was used for buyers was the predicted probability of purchasing a private substitute from the estimation function reported in Table 4, and the share that was used for non-buyers was consequently 1 minus the predicted probability.

The simulated curves shown in Figure 3 illustrate the impact of the air purifier purchase decision, and those in Figure 4 report the impact of the mask purchase decision. Clearly, distinguishing buyers from non-buyers reproduces the tendency illustrated in Figure 2. For the air purifier case, buyers' WTP decreases with income whereas non-buyers' WTP increases, and it is actually the relatively poorer buyers who have the highest WTP overall. For the mask case, consistent with Figure 2, both buyers' and non-buyers' WTP increases with income, but the increasing trend seems to be more pronounced for non-buyers.

When we compare WTP\_weighted average to WTP1 in Figure 3 we can see that the heterogenous income elasticity caused by private substitute purchasing and the variation in

the probability of private substitute consumption lead the curvature of the WTP-income curve to bend downward much earlier. With such a WTP-income trajectory, we should expect a Pigou-Dalton transfer from the wealthiest households to the poorest households to lead to a larger increase in societal mean WTP.

When it comes to the mask purchase decision (c.f. Figure 4), however, the WTP\_weighted average stays above the WTP1 line over the entire income range, which shows an increasing trend very similar to that of WTP but with a slightly more concave curvature. This small change in the curvature of the WTP\_weighted average curve can be explained by the very low price of masks, which makes the mask purchase decision relatively trivial when it comes to determining people's WTP for better air quality, both at the individual level and the population mean level.

## **7. Conclusion and discussion**

In this paper, we proposed a nested constant elasticity of substitution (CES) utility function to differentiate a private environmental substitute from ordinary private consumption goods by assuming closer substitutability with environmental quality. Our theoretical model showed that the income elasticity of buyers' WTP decreases with their income and increases with the price of the private environmental substitute. These two factors also influence the decision to purchase private environmental substitutes. More specifically, the probability of buying a private environmental substitute increases with income and decreases with the price of the private substitute.

Our theoretical model's findings were confirmed by an empirical check, based on a CVM survey of people's WTP for better air quality in the city of Nanjing, China. Our simulation demonstrated that the consumption of air purifiers tends to reduce societal mean WTP in a more inequal economy, while the consumption of masks has only a very marginal influence.

Our study's findings remind us of the importance of inquiring about the existence of expensive closer private environmental substitutes and the public's consumption behavior of said substitutes in stated preference surveys. This information will also be very useful for understanding the consumption style of households at different income levels with regard to said substitutes. A similar strategy is frequently used in travel cost methods, in which researchers often invite participants to report similar sites as potential substitutes for the one being studied.

The necessity of such a strategy may also depend on the nature of the environmental goods to be evaluated. Although air purifier can be viewed as a (partial) private solution to alleviate the negative impact of air pollution, substitution might be more difficult for other environmental goods. Take natural surface water as an example. While a private swimming pool could be regarded as a plausible private substitute candidate for natural surface water quality, we assume that it may be an overly expensive private solution in countries in Asia and Europe where the population density is relatively high and water resources are scarce. At the same time, we may also believe, to a certain extent, that the capacity to enjoy better natural surface water quality increases with income; in other words, better surface water

quality may be a complement for many private goods, including private vehicles. This may drive the income elasticity of wealthier households' WTP higher, since such natural environmental goods become more accessible with income. In a same vein, the geographical distribution of the environmental good in question can also play a role. Meya (2020) described an interesting and plausible situation in which the spatial distribution of public environmental goods is heterogenous. For example, richer households may live closer to bodies of natural surface water and therefore be able to benefit more from a public policy to improve the quality of these waterbodies. This is very different from the air pollution situation, whose spatial distribution is more homogenous or, as some authors have suggested, more densely present in poorer communities (Hajat et al., 2015). All these logics are somewhat supported in related works such as Ready et al. (2002), Czajkowski and Scasny (2010) and Barbier et al. (2017), all of which investigate surface water quality improvement projects in Eastern Europe and report the income elasticity of WTP to be less than one but *increase* with income, which is opposite to what we found in this study for WTP for air quality improvement.

Our empirical findings share similarities with evidence from laboratory public-good experiments. Several previous papers analyzing the impact of asymmetric endowments on the voluntary contribution mechanism have demonstrated that income inequality can affect an individual's contribution to public interest. Buckley and Croson (2006) based their work on the inequality aversion model and the altruism model and found that less-wealthy subjects give the same absolute amount (and more as a percentage of their income) as wealthier ones do. More closely related to our results, Keser et al. (2013) similarly reported

that the “rich” players in a public goods game contribute a significantly lower percentage of their endowment than the other players do. In addition, Hargreaves Heap et al. (2016) and Cherry et al. (2005) found that in a voluntary public goods game, endowment-heterogeneous groups contribute significantly less than endowment-homogeneous groups do, and the high-endowment individuals in the endowment-heterogeneous groups contribute less than the other group members do. Zelmer (2003) conducted a meta-analysis of 27 primary studies of linear public goods voluntary contribution mechanism experiments and found that the maximized individual payoff is significantly negatively affected by heterogeneity in the initial endowment arrangement.

Our theoretical model has some limitations. First, our model used a nested CES function to describe people’s utility. Although such function form is well adapted to the consumption behavior generally observed, it is still a specific function form. One concern is how this specific function form can limit generalizability of our findings. We are comforted in this regard by the fact that our findings seem to echo the conclusion reached by Ebert’s (2003) and Flores & Carson’s (1997), both adopting a more general function form. Second, our model was designed to consider discontinuous decisions (1/0) to purchase a private environmental substitute. Future research could expand our model to consider continuous decisions to purchase private environmental substitutes.

Finally, we cannot exclude the possibility that the phenomenon documented in this paper is unique to China. First, this study was conducted in 2015-2016, when most large Chinese cities were suffering from extremely serious air pollution problems. The decision to

purchase an air purifier might have been more urgent in that context. As a result, we do not know the extent to which our results can be generalized to other places. It might therefore be interesting to test our assumptions in other regions and countries and on other environmental goods. Second, we are not aware of the extent to which the results observed in this paper may be related to the generally observed low level of public trust in the local government in Nanjing. Wang et al. (2020) showed the low level of trust the public had in the municipal government's ability to carry out an air quality improvement project could lead to significantly lower levels of mean WTP. Although their survey was conducted in two other cities in China, we suspect that similar concerns among Nanjing residents may have further motivated some wealthier households to adopt private preventive measures. It is, however, unfortunately not possible for us to distinguish these two channels with our dataset. Future research therefore needs to add more quality control in the form of following-up questions after the WTP question, particularly one about people's perceived policy consequentiality. This will make it possible to better distinguish between these two potential channels.

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**Table 1. Descriptive statistics (N=1671)**

Variable	Definition	Mean	Std. Dev.	Min	Max.
Response	response to WTP question (yes=1, no=0)	0.46	0.50	0	1
Ln(Bid)	bid price in logarithm <sup>1</sup>	5.70	2.23	2.30	9.21
Ln(income)	Monthly household income in logarithm	8.87	0.89	5.52	10.82
Mask	used mask as preventive measures in the past two years	0.10	0.30	0	1
Air purifier	installed air purifier system at home in the past two years	0.15	0.35	0	1
Male	Gender	0.48	0.50	0	1
Age	age in years	26.9	7.75	18	73
Married	marrital status (married=1, other=0)	0.33	0.47	0	1
University	education level, college education or above=1, other=0	0.85	0.36	0	1
Outdoor worker	full or partial outdoor worker=1, indoor worker=0	0.25	0.44	0	1
Nanjing resident	Nanjing permanent resident=1, other=0	0.46	0.50	0	1
Diseases	Having long-term respiratory diseases. Yes=1, No=0	0.07	0.25	0	1

1. bid=10, 20, 50, 100, 200, 500,1000, 2000, 5000 and 10000 Yuan/year. The exchange rate in 2016 was 1USD=6.65Yuan.

**Table 2. WTP determination function**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ln(income) ( $\alpha$ )	0.296** (0.149)	0.303* (0.162)	0.334** (0.159)	0.278* (0.155)	0.332** (0.165)	0.346** (0.163)	0.307* (0.158)
Ln(income)[0-4000]*Air purifier ( $\gamma_1$ )		0.281** (0.116)	0.279** (0.114)				
Ln(income)[4000-8000]*Air purifier ( $\gamma_1$ )		0.167*** (0.0636)	0.177*** (0.0619)				
Ln(income)[8000-25000]*Air purifier ( $\gamma_1$ )		0.0974 (0.0659)	0.107* (0.0649)				
Ln(income)[25000over]*Air purifier ( $\gamma_1$ )		-0.0581 (0.112)	-0.0561 (0.0948)				
Ln(income)[0-4000]*Mask ( $\gamma_2$ )		0.00134 (0.0998)		0.0411 (0.0973)			
Ln(income)[4001-8000]*Mask ( $\gamma_2$ )		0.0709 (0.0762)		0.113 (0.0743)			
Ln(income)[8001-25000]*Mask ( $\gamma_2$ )		0.107 (0.0922)		0.122 (0.0907)			
Ln(income)[25000over]*Mask ( $\gamma_2$ )		0.0310 (0.147)		-0.0313 (0.126)			
Ln(income)*Air purifier ( $\gamma_1$ )					1.169** (0.482)	1.140** (0.444)	
Ln(income) <sup>2</sup> *Air purifier ( $\gamma_1$ )					-0.111** (0.0511)	-0.107** (0.0470)	
Ln(income)*Mask ( $\gamma_2$ )					-0.0267 (0.519)		0.375 (0.474)
Ln(income) <sup>2</sup> *Mask ( $\gamma_2$ )					0.00895 (0.0562)		-0.0321 (0.0512)
Male	-0.820*** (0.267)	-0.853*** (0.268)	-0.872*** (0.267)	-0.797*** (0.267)	-0.867*** (0.269)	-0.878*** (0.268)	-0.810*** (0.268)
Age	-0.0557** (0.0237)	-0.0485** (0.0236)	-0.0502** (0.0236)	-0.0533** (0.0237)	-0.0489** (0.0237)	-0.0505** (0.0237)	-0.0535** (0.0237)
Marriage	0.295 (0.376)	0.114 (0.378)	0.117 (0.378)	0.273 (0.376)	0.132 (0.379)	0.130 (0.378)	0.283 (0.376)
University	0.364 (0.378)	0.367 (0.378)	0.368 (0.378)	0.356 (0.378)	0.379 (0.379)	0.378 (0.379)	0.362 (0.378)
Outdoor worker	-0.0747 (0.301)	-0.0568 (0.301)	-0.0507 (0.301)	-0.0874 (0.301)	-0.0694 (0.302)	-0.0601 (0.301)	-0.0998 (0.301)
Nanjing resident	-0.252 (0.282)	-0.314 (0.282)	-0.303 (0.282)	-0.260 (0.282)	-0.322 (0.283)	-0.317 (0.283)	-0.257 (0.283)
Disease	-0.306 (0.522)	-0.333 (0.525)	-0.309 (0.522)	-0.362 (0.524)	-0.329 (0.526)	-0.299 (0.524)	-0.380 (0.524)
Constant	4.472*** (1.544)	4.227** (1.659)	3.979** (1.638)	4.582*** (1.596)	3.979** (1.682)	3.889** (1.663)	4.328*** (1.616)
sigma	3.876*** (0.234)	3.846*** (0.232)	3.850*** (0.232)	3.869*** (0.234)	3.863*** (0.234)	3.862*** (0.233)	3.876*** (0.234)

Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial log likelihood	-1010.03	-1010.03	-1010.03	-1010.03	-1010.03	-1010.03	-1010.03
Final log likelihood	-981.18	-971.68	-972.75	-979.10	-972.30	-973.25	-979.63
Pseudo R2	0.1490	0.1572	0.1563	0.1508	0.1564	0.1559	0.1503
BIC	2177.57	2217.94	2190.41	2203.10	2190.11	2176.55	2189.31
Observations	1671	1671	1671	1671	1671	1671	1671
Mean WTP	187Yuan	196 Yuan	196 Yuan	187 Yuan	198 Yuan	198 Yuan	189 Yuan
Mean ln(WTP)	5.23	5.28	5.28	5.23	5.29	5.29	5.24
CI of ln(WTP)	[4.97 5.48]	[5.01 5.54]	[5.03 5.54]	[4.98 5.48]	[5.03 5.55]	[5.03 5.55]	[4.98 5.49]
Mean_WTP_air_purifier		699Yuan	773 Yuan		750Yuan	821Yuan	
Mean ln(WTP)_air purifier		6.55	6.65		6.62	6.71	
CI of ln(WTP)_air purifier		[5.72 7.39]	[5.86 7.45]		[5.78 7.44]	[5.93 7.52]	
Mean WTP_mask		242 Yuan		365 Yuan	237Yuan		388Yuan
Mean ln(WTP)_mask		5.49		5.90	5.47		5.96
CI of ln(WTP)_mask		[4.63 6.34]		[5.08 6.74]	[4.57 6.37]		[5.13 6.82]
Mean WTP_wo_air_purifier_mask		150 Yuan	156 Yuan	174 Yuan	150 Yuan	156 Yuan	174 Yuan
Mean ln(WTP)_wo_air purifier_mask		5.01	5.05	5.16	5.01	5.05	5.15
CI of ln(WTP)_air_wo_purifier_mask		[4.71 5.29]	[4.77 5.33]	[4.89 5.42]	[4.72 5.29]	[4.77 5.32]	[4.88 5.42]
Mean WTP_air_purifier_mask		1141 Yuan			1200 Yuan		
Mean ln(WTP)_air purifier_mask		7.04			7.09		
CI of ln(WTP)_air purifier_mask		[5.98 8.06]			[6.03 8.16]		

Note: The estimations are based on the maximum likelihood function given in eq. (18), so the coefficients reported in the table can be directly interpreted as how the related variables affect the ln(WTP). Robust standard errors in the parentheses. \* p<0.10, \*\* p<0.05 and \*\*\*p<0.01. Mean WTP is calculated based on the total sample mean value of the related variables. The exchange rate was 1USD=6.65 Yuan in 2016.

**Table 3. Comparison of income between respondents adopted private environmental substitute**

	<b>Nb. Obs</b>	<b>Mean income</b>	<b>Standard Deviation</b>	<b>Difference (T value)</b>
<b>Air purifier</b>				
Installed	243	14982.51	13269.61	5738.81***
Not installed	1428	9243.70	8612.24	(8.77)
<b>Mask</b>				
Bought	172	12395.25	12648.16	2582.97***
Not bought	1499	9812.38	9204.23	(3.34)

Note: The exchange rate in 2016 was 1USD=6.65Yuan

**Table 4. Decision to buy substitute good of air quality (Probit)**

	<b>Air purifier</b>	<b>Mask</b>
Ln(income)	0.290*** (0.0491)	0.125** (0.0491)
Male	0.102 (0.0800)	-0.118 (0.0870)
Age	-0.0148** (0.00738)	-0.0311*** (0.00965)
Married	0.475*** (0.110)	0.0458 (0.131)
University	0.00417 (0.115)	0.0295 (0.130)
Outdoor worker	0.0122 (0.0914)	0.183* (0.0954)
Nanjing resident	0.141* (0.0848)	0.0565 (0.0915)
Disease	0.0741 (0.152)	0.534*** (0.148)
Constant	-3.578*** (0.465)	-1.670*** (0.478)
Pseudo R2	0.061	0.034

Robust standard errors in the parentheses. \* p<0.10, \*\* p<0.05 and \*\*\*p<0.01. Mean WTP is calculated based on the total sample mean value of the related variables.

**Figure 1. % of respondents having purchased substitute good in the past two years**

**Figure 2. Evolution of WTP with income based on the private environmental substitute purchase decisions** (The exchange rate in 2016 was 1USD=6.65Yuan)

**Figure 3. Impact of the purchase decision of private substitutes on the relationship between predicted WTP and household income: Purchase decision of air purifier**  
(Note: The exchange rate in 2016 was 1USD=6.65Yuan)

**Figure 4. Impact of the purchase decision of private substitutes on the relationship between predicted WTP and household income: Purchase decision of mask**

(Note: The exchange rate in 2016 was 1USD=6.65Yuan)

## Endnotes

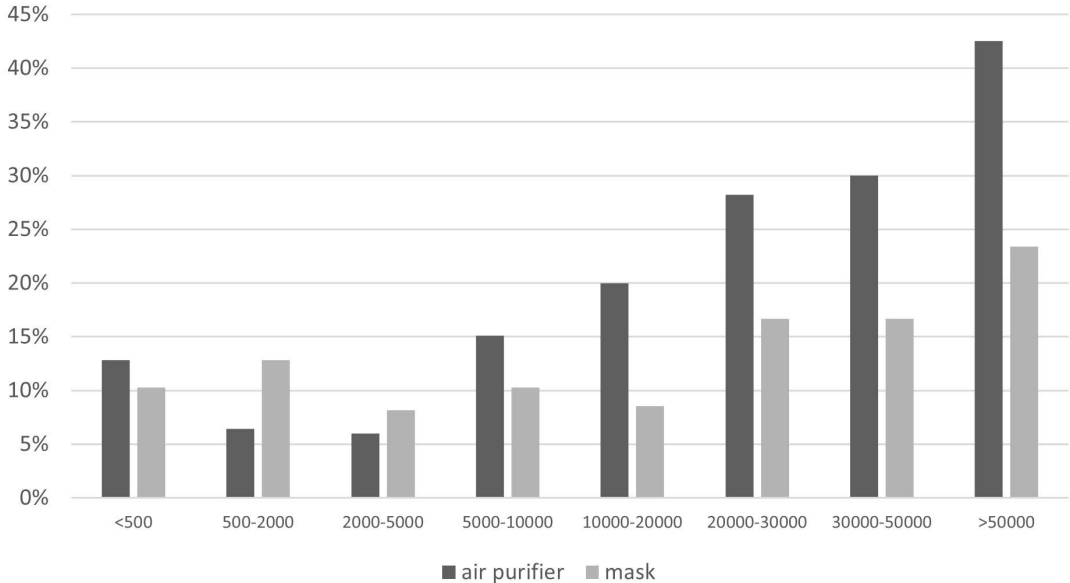
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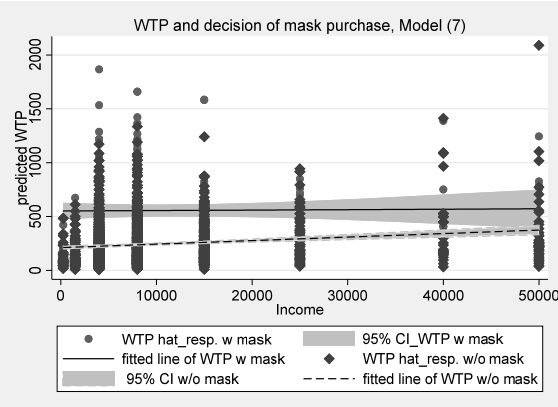
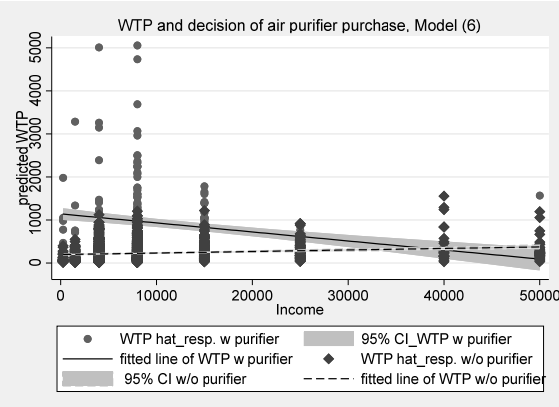
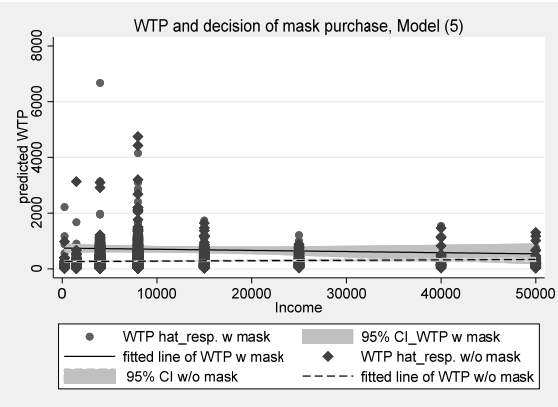
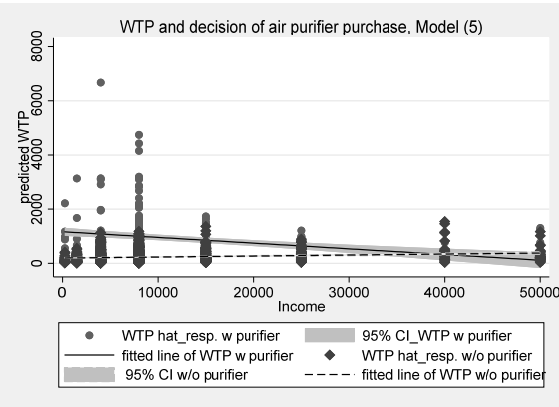
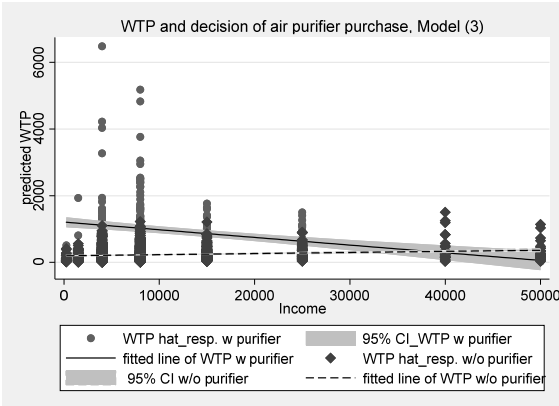
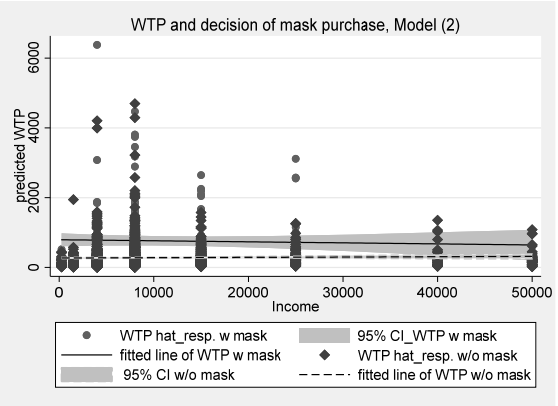
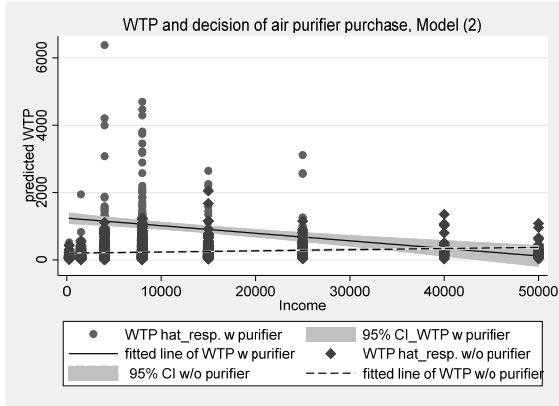
<sup>i</sup> We also know that both the buyer's and the non-buyer's income elasticity of  $\varphi$  (i.e., income elasticity of marginal WTP) is equal to the income elasticity of WTP.

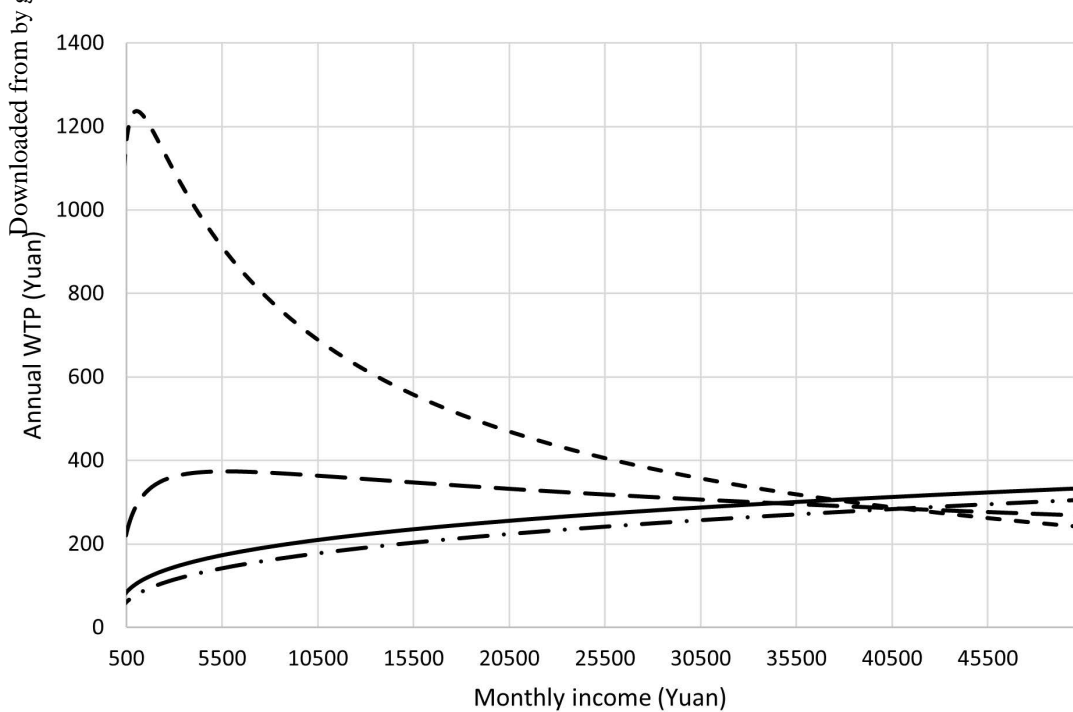
<sup>ii</sup> In the first edition of the survey, we set the highest fee amount at 5,000 Yuan per *season*. This was based on a focus group discussion in which all members believed that 5,000 Yuan per season, or 20,000 Yuan per year, was a very high fee and that very few respondents would be willing to pay that amount. The answers collected in the first edition showed that only 77 of the 751 respondents that were proposed the fee of 5,000 Yuan per season answered yes. Another critical piece of feedback from the first edition was that some respondents seemed to be less accustomed to seasonal payments. We therefore decided to use an *annual* fee in the second edition and set the highest amount at 10,000 Yuan per year.

<sup>iii</sup> Since our paper is interested in understanding how the income elasticity of WTP is related to people's decision to purchase private environmental substitutes, we decided to not include the dummy variables identifying people's purchase decision apart from in the cross-terms with  $\ln(\text{income})$  to allow the correlation between people's WTP and their private environmental substitute purchase decisions to be captured entirely by the income elasticity of their WTP. So, our empirical models should in no way be interpreted as capturing any causal relationship between WTP and private environmental substitute consumption. In fact, we believe there are multiple observable and non-observable factors that can be considered confounders that potentially influence both people's WTP for public environmental goods and their decision to buy private environmental substitutes.

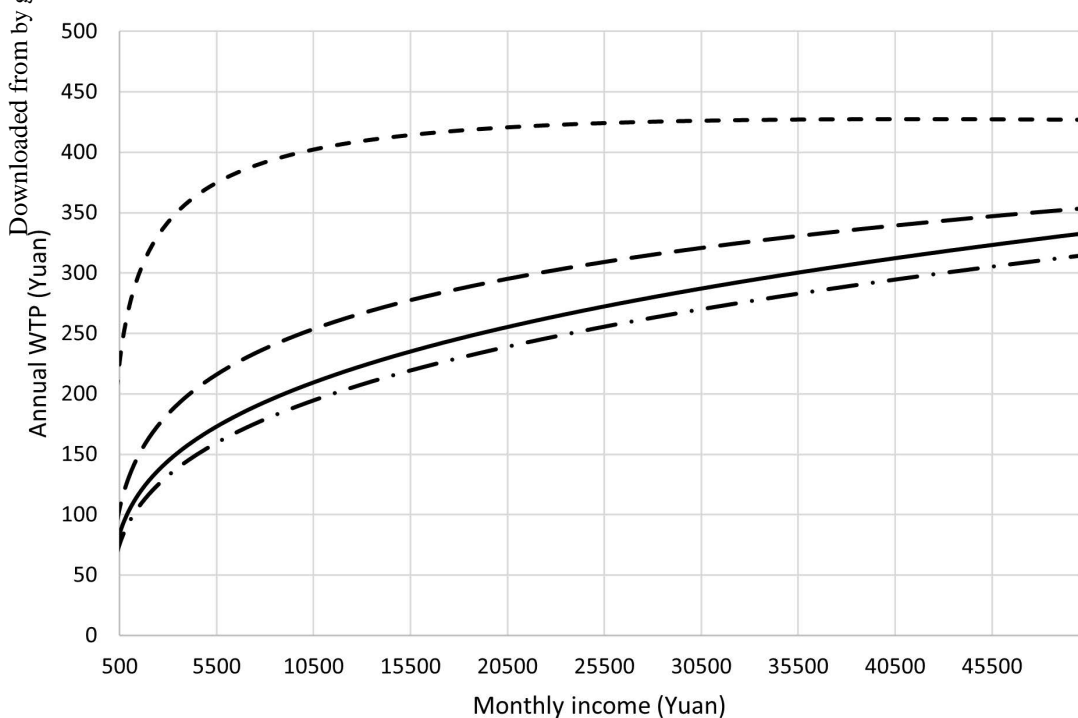
<sup>iv</sup> We tried different intervals for the income range reported in our database. The table presents the most satisfactory results.







- WTP\_constant income elasticity (Table 2, Model 1)
- · - WTP\_non\_buyer (Table 2, Model 6)
- - - WTP\_buyers (Table 2, Model 6)
- - - WTP\_weighted average (Table 2, Model 6) with predicted share of buyers (Table 4, Model 1)



- WTP\_constant income elasticity (Table 2, Model 1)
- · - WTP\_non\_buyer (Table 2, Model 7)
- - - WTP\_buyers (Table 2, Model 7)
- - - WTP\_weighted average (Table 2, Model 7) with predicted share of buyers (Table 4, Model 2)