Reference point adaptation and air quality – Experimental evidence with anti-PM 2.5 facemasks from China

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Abstract

The formation of reference points has drawn increasing interest ever since the introduction of prospect theory. Given that most studies focus on tradable goods such as stocks, for which the prices are observable, while few have focused on environmental goods. This paper attempts to fill this gap in the literature in this regard.

In our experiment, we divided the subjects into buyers and sellers and asked them to trade four PM 2.5 filters using the Becker–DeGroot–Marschak mechanism. We have two treatments in this experiment: a) the experience of seven weeks of heavy air pollution; and b) the receiving of information on the relationship between death rates and air pollution. The different bidding prices for the four PM 2.5 filters in these treatment groups make it possible to trace the adjustment of the reference points as a result of these treatments without having to know their precise values.

Our results show that, for buyers, the heavy air pollution drives them to fully downwardly adjust their reference points on air quality. For sellers, however, the reference points adaptation caused by heavy pollution is not a full adaptation. Moreover, the new information on the damage to health from air pollution causes buyers to upwardly adjust their reference points on air quality but does not significantly change the sellers' reference points.

We show that, for both treatments, sellers are more reluctant to adjust their reference points on air quality than are buyers. Our results confirm the asymmetric reference point adaptation in that adaptation after a loss is harder than adaptation after a gain.

Keywords:

prospect theory; reference point; asymmetric adaptation; air pollution; BDM auction

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1. Introduction

According to prospect theory (Kahneman and Tversky, 1979), the utility does not depend on the absolute amount of consumption, but rather on the relative consumption compared with a reference point. Researches with stock trading have verified that reference points can be shaped by the status quo, expectations, and other factors, such as social norms (Arkes et al., 2008; Abeler et al., 2011; Bartling and Schmidt, 2015). Moreover, the reference points are not static and can be updated endogenously when a new situation arises.

Most of the studies on reference points adaptation are conducted in the fields of stock trading. To the best of our knowledge, there are no studies on how reference points in relation to public goods, such as air pollution, are formed and updated. As a non-market good, the valuation of air pollution has been an important topic in environmental economics.

The different reference points may result in different valuation for air quality. For example, according to one of the authors' personal experiences of living in both Xi'an and Taipei, the same level of air quality will give rise to different feelings among the residents in the two cities. For example, an air quality index (AQI) of 100 would be normal in Xi'an but would be considered to constitute heavy pollution in Taipei. Another example is that the more one knows about the damage to health brought about by air pollution, the worse one will feel when confronted with polluted air. This naturally raises the question of whether people exposed to different pollution levels exhibit different reference points. Similarly, would the reference points change as people learn more about the damage to health resulting from air pollution?

In this paper, we will test two hypotheses regarding the adaptation of the reference points in relation to air quality with a lab experiment:

Hypothesis 1: People will fully downwardly adjust their reference points regarding air quality after seven weeks of heavy pollution.

Hypothesis 2: People will upwardly adjust their reference points upon receiving new information regarding the damage caused by air pollution.

As there is no market for clean air, we cannot directly observe the willingness to pay for clean air. However, consumers' purchasing behavior in relation to anti-PM 2.5 masks, which is the most widely accepted and cheapest way of reducing the damage to health from air pollution in China, helps reveal their valuations for clean air.

In our experiment, we use a special mask from which the PM 2.5 filters can be separated. We randomly divide the subjects into buyers and sellers and ask them to trade the four PM 2.5 filters using the BDM (Becker–DeGroot–Marschak method, Becker et al., 1964) procedure. The BDM auction is incentive compatible, which allows us to find out the intrinsic values of both buyers (willingness to pay, WTP) and sellers (willingness to accept, WTA) for the four PM 2.5 filters. We use a two by two experiment design and vary two variables, the air pollution level and the new information regarding the damage caused by air pollution. We find that seven weeks of heavy pollution had driven buyers completely to adjust their reference points downwards, and the new information about the damage caused by air pollution made them adjust their reference points upwards. While for sellers, seven weeks of heavy pollution did not make them fully adapt to the worse air quality, and the new information about the health damage of air pollution did not help them adjust their reference points upwards significantly. We also find evidence of asymmetric adaptation among sellers and buyers: sellers are more reluctant to adjust their reference points than are buyers for both treatments.

This study fills a gap in the literature on reference point adaptation in relation to environmental goods. It also adds to the literature of asymmetric adaptation in reference points. Our findings have important implications regarding the valuation of environmental goods, where reference points matter. In the next section, we will review the literature on reference points formation. In sections three and four, we introduce the experiment design and results. We conclude in section five.

2. Literature review

Based on numerous lab experiments and observations on the behaviors of people, Kahneman and Tversky (1979) came up with prospect theory. It corrects the drawbacks of expected utility theory in explaining the reverse of risk preference. The reference points-based prospect theory is confirmed by researchers and is the best-performing model in explaining behaviors under risk and uncertainty (Wakker, 2010). Prospect theory has resulted in three main findings. First, in the gain domain, people are risk-averse, and the valuation function is concave as in expected utility theory. In the loss domain, people become risk-loving, as indicated by a convex utility curve. Secondly, the pain from losing something is greater than the happiness from gaining it. Thirdly, the reference point decides whether a person is in the gain domain or in the loss domain. If the situation is better than his/her reference point, he/she is in the gain domain; otherwise, he/she is in the loss domain. The reference point is the key to prospect theory. It is the relative consumption (such as wealth, health, and the environment) compared to the reference point that decides how people feel, rather than the absolute amount of these goods consumed.

Kahneman and Tversky (1979) suggest several possible ways in which reference points are formed, such as the status quo, social norms, and aspirations. There are mainly four hypotheses in the literature regarding the formation of the reference point: the status quo or lagged status quo, expectations, goals or aspirations, and multiple reference points.

The status quo hypothesis is that people will choose the current situation to which they have become well adapted as the reference point. For example, Kahneman & Tversky (1979) suggest that an individual's current wealth can serve as the reference point. Brickman et al. (1978) find that, although disabled people may go through a tough time, they will gradually adapt to new situations and are not significantly less happy than non-disabled people. Sherman et al. (2019) find that, after some time of adaptation, lottery winners are not significantly happier than those who did not win the lottery. They claim that relative wealth, rather than absolute wealth, has a greater effect on happiness. Here the adaptation process reflects the adjustment of the individual's reference point from his/her historical wealth status to the current wealth status.

Many studies have found that the reference point can be affected by expectations. For example, Ng and Wang (1993) have found that failing to meet a high expected future consumption will greatly reduce happiness. Hack and Lammers (2009) study the role of expectations in the formation of reference points using both surveys and experiments. They find that expectations have a significant impact on reference point formation and subsequent risky choices. Köszegi and Rabin (2006) model choice under uncertainty with reference-dependent preferences where the reference point is determined endogenously by the rational expectations. They apply the model to consumer behavior and labor supply decisions and find that higher expectations increase the willingness to pay as well as the within-day labor supply. Abeler et al. (2011) assume that the individual's reference point is a function of his expectations and test this using a real-effort laboratory experiment. They find that people put in more effort when they have higher expectations. Bartling and Schmidt (2015) find strong evidence that professional soccer players and their coaches use contracts as the reference point when negotiating, and the reference point helps shape their expectations. Hack and von Bieberstein (2015) employ both indirect and direct approaches to examine prospect theory and find that decision-makers use expected values when forming reference points.

Aspirations or goals are also found to help shape the individual's reference point. For instance, Camerer et al. (1997) find that taxi drivers in New York City set a loose daily income target and stop working once they reach that target for that day. Heath et al. (1999) find evidence of goals serving as reference points and help explain previous empirical results on effort, persistence, and performance. Hack et al. (2016) find that entrepreneurs tend to set more aspiring reference points and are more intent on forming new ventures than are managers. Allen et al. (2017) find that round numbers serve as reference points in marathons and affect the provision of effort near the finish line.

At the same time, many studies find that other factors like social norms and historical prices can also serve as reference points. In addition, many studies find that a person has multiple reference points simultaneously and will adapt to new reference points endogenously. Post et al. (2008) find that reference levels in choices under risk are path-dependent. Arkes et al. (2008) find that people tend to adjust reference points upwards after gains and downwards after losses in relation to stock investment with or without monetary incentives, and adaptation to gains takes place more quickly and on a larger scale than adaptation to losses. Baucells et al. (2011) find that the first trading price and the last trading price have a large weight in the reference point formation in stock trading. Bartling and Schmidt (2015) find that social norms could be the potential reference points in contract renegotiations. Lim et al. (2019) find that when societal values are present, the effect of income on happiness is moderated and becomes insignificant.

An increasing number of studies on reference points have been conducted with surveys, lab experiments and field experiments in domains such as stock trading (Arkes et al., 2008; Baucells et al., 2011; Terzi et al., 2016) and effort provision (Abeler et al., 2011; Allen et al., 2017). However, to the best of our knowledge, there are no such studies in the domain of non-market goods or environmental goods, such as climate change and air pollution. To examine the adaptation of reference points in regard to air pollution, we have designed a lab experiment with the BDM procedure to reveal the changes in the reference points based on two treatments: one is the status quo, and the other is a new information shock. Although it is difficult to locate the reference points directly, the changes in the intrinsic value of the PM 2.5 filters among different treatment groups can help reveal the adjustments to the reference points.

3. Experiment design:

We recruited subjects for this experiment by putting up ads at the entrance of every dormitory and the entrance of each school cafeteria on this campus, ending up with 187 subjects recruited from Xi'an Jiaotong University. Both undergraduate and graduate students have been included. Our experiment uses a between-subject design. There are four sections in this experiment. In each of the four sections, we randomly divided students into buyers and sellers and asked them to trade the PM 2.5 filters with instructors. We have informed the subjects that the participation fee is 20 yuan and buyers who bid more than 20 yuan may need to use their pocket money. The timeline for the four sections is based on the background of the home heating system in northern China, which serves as our first treatment. Our second treatment is the extra information on the relationship between death rates and air pollution for Section 2 and Section 4. The four sections and the two treatments are arranged in Table 1 as follows:

Table 1: Experiment design

	Without extra health damage information	With extra health damage information
Before the heating season starts	Section 1 (N=53)	Section 2 (N=60)
After the heating season starts	Section 3 (N=43)	Section 4 (N=31)

The number of observations is in brackets.

3.1 Background to the experiment

In China, the current home heating system is largely shaped by the Huai River home heating policy. The Huai River home heating policy was introduced in 1950, aiming to provide coal-based heating for homes and offices in northern China during the heating season (from November 15 to March 15). Today the heating system in China still relies on the thermal power plant as the main source of heating. Consequently, the air pollution resulting from coal-burning during the heating season has become a serious problem in China (Chen et al., 2013). The air quality in cities in northern China is usually worse in the heating months than in the other months. Our experiment was conducted in Xi'an, a major city in northwest China where the heating policy applies. Figure 1 shows how the air quality varied in Xi'an from March 15, 2017, to March 15, 2018. We can see that the air quality in the heating season is on average worse than in the non-heating season.

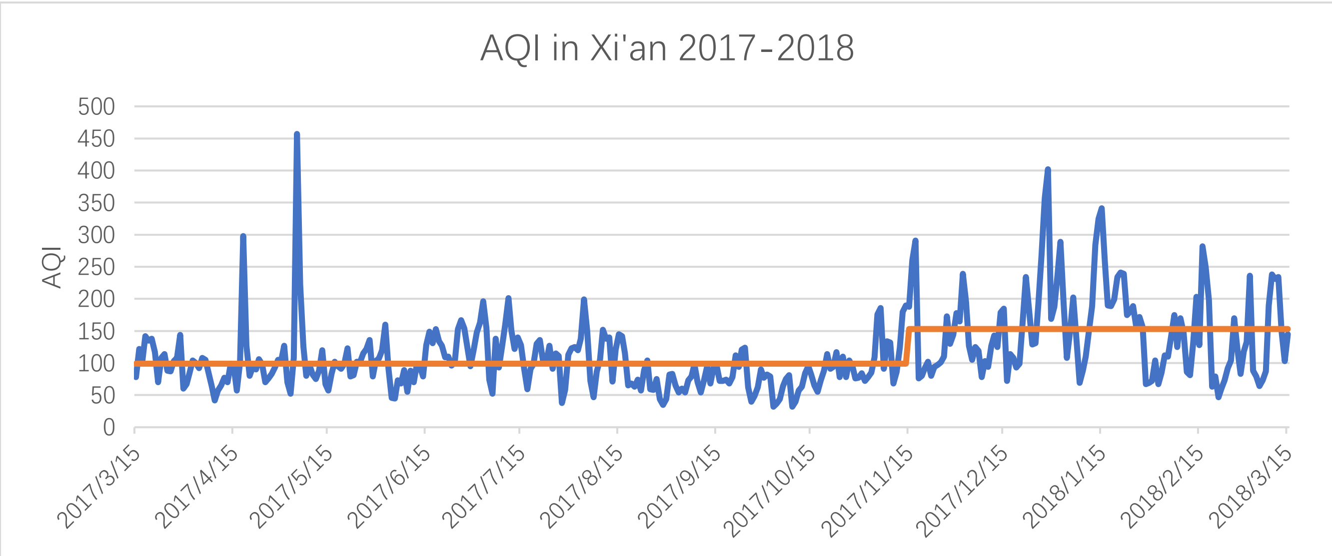


Figure 1. The AQI in Xi'an from 2017-2018

Data source: http://data.epmap.org/eia/air

In our experiment, the first two sections were conducted on November 8, 9, and 12, 2018, about one week before the start of the heating season. Usually, during this week, the heating system will be tested to check whether it is functioning well. The air quality usually deteriorates in this week and remains at a low level during the heating season. The last two sections were conducted on December 26, 2018, about seven weeks after the start of the heating season. The subjects in the last two sections experienced having been exposed to some heavy air pollution.

We collected daily AQI data for the specific moments we conducted our experiments (between 7–8 p.m.) from the nearest air quality monitoring station (Xingqing Xiaoqu station), as shown in Figure 2. Based on the standards of either the US or China, an AQI between 150 and 200 is unhealthy; an AQI between 200 and 300 is very unhealthy, and an AQI over 300 is hazardous. Thus, during the 48 days in between, we have 2 hazardous days, 9 very unhealthy days, and 17 unhealthy days.

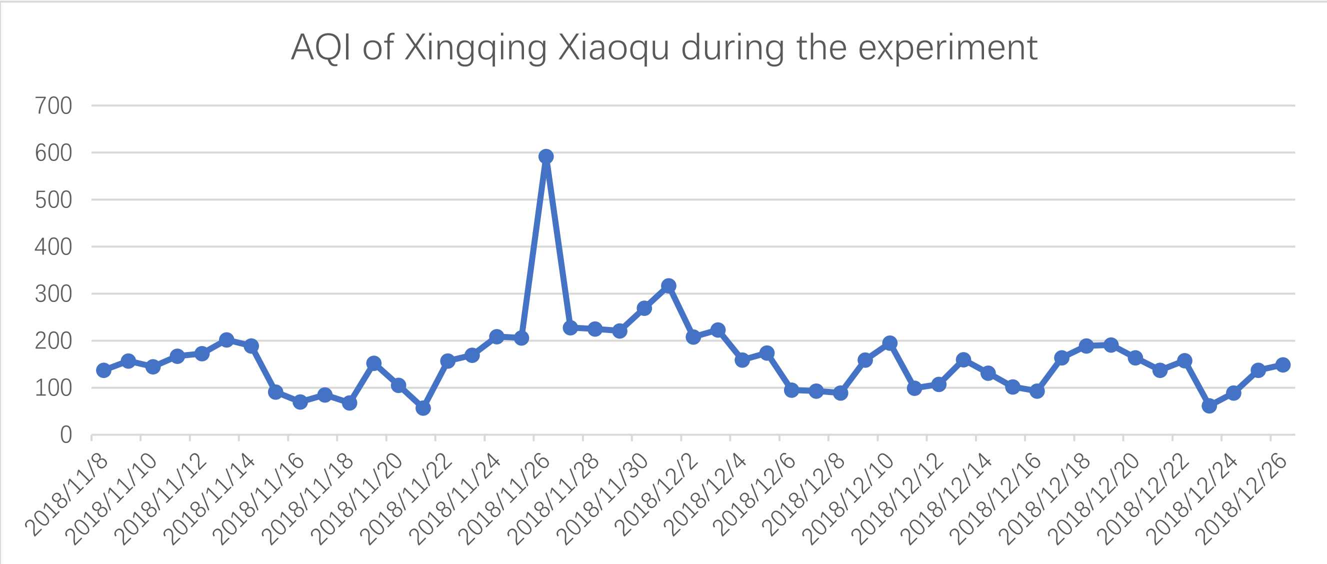


Figure 2. AQI during the experiment.

Source: https://aqicn.org/city/china/xian/xingqingxiaoqu/

We chose the facemasks used in the experiment carefully. There are two types of anti-PM 2.5 facemasks in the Chinese market. One is that the filters can be separated from the masks. The other one is the popular non-detachable masks such as the 3M masks, N95 masks, and KN95 masks. We chose the less known detachable masks so that the subjects were less affected by the market price. Besides, the masks were sold with four filters as a package and the filters alone were not for sold. Another advantage of the detachable masks is that they allow us to isolate the function of filters from the masks. People also use masks to keep their cheeks warm during the winter. We trade the filters to value the function of filtering the particulate matter exclusively.

3.2 Procedures for the experiment

Before the experiment started, the students entered the classroom and found a random seat. We randomly divided the students into buyers and sellers using the last digit of their student ID numbers. Then we introduced the purpose of the experiment, the privacy concerns regarding their personal information, and how the payment would be made. After that, the students decided whether to participate in this experiment or not. Those choosing to stay were asked to sign an agreement that was placed on their desks. The total earnings in the experiment were comprised of a fixed fee of 20 yuan for showing up plus the earnings from the trading.

At the beginning of each section in this experiment, we gave them a sheet of paper containing basic information on the health effects of air pollution (see Appendix 1). Then we introduced the BDM procedure to the subjects with examples, followed by a simple quiz to make sure they understood it. The instructors were to check these answers one by one and explain to the students in person if they had incorrectly answered the questions. After making sure everyone was clear about the rules, there were two rounds of practice with a hypothetical good (a token) for them to become familiar with the procedures. For Sections 2 and 4, we gave the students a piece of paper regarding the relationship between death rates and air pollution before starting the real experiment. The information was collected from the World Health Organization website (https://www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/) and is presented in Appendix 2.

In the real experiment, every student received a mask together with four PM 2.5 filters (each one can last for about a week). The sellers could keep both the mask and the four filters, while the buyers needed to give the four filters back to the instructors and were only able to keep the mask. By applying the BDM procedure, we asked the buyers to decide how much they wanted to pay (WTP) for the four filters and write down the answers on the sheet; as for the sellers, we asked them at what price they wanted to sell (WTA) the four filters and write the answers on the sheet. The bidding price was to be between 1 and 40 yuan. After they decided their bidding prices, we randomly drew a market price of between 1 and 40 yuan. As for the buyers, if a buyer's bid was higher than (or equal to) the market price, then he/she could buy the four filters from the instructors and pay the market price; if his/her bid was lower than the market price, then he/she could not buy the four filters and the trade did not take place. As for the sellers, if a bid was lower than (or equal to) the market price, the seller could sell his/her four filters to the instructors at the market price; if the bid was higher than the market price, the trade could not take place and the seller could not sell his/her four filters. Each section had five rounds. After all five rounds were over, we chose one of them randomly as the final result and traded with the buyers and sellers using real money. For example, if Round 4 was chosen and the market price in this round was 30 yuan, then all buyers whose bids were higher than (or equal to) 30 were able to buy four filters from the instructors and pay 30 yuan. At the same time, all sellers whose bids were lower than (or equal to) 30 were able to sell their filters to the instructors and receive 30 yuan. At the end of the experiment, we collected some basic information about each student using a survey, including his or her age, gender, habits regarding exercising, and so on. The experiment's instructions and the survey are provided in Appendix 1.3.

3.3 Value function for the four sections

We assumed that the individual's valuation function regarding air quality did not change and is depicted as shown in Figure 3. $V = V(Q - Q_0)$, where Q_0 is the initial reference point regarding air quality, Q refers to the current air quality, and V is the individual's valuation of the relative air quality, which is equal to the WTP (for buyers) or the WTA (for sellers). Since air quality is a normal good, we have $V'(Q) > 0$. In our experiment, all students had positive biddings for the PM 2.5 filters, suggesting that they are in the loss domain, and the current air quality is worse than their initial reference points. Thus, we have $Q < Q_0$ and $V < 0$, and $WTP(WTA) = |V| = -V$.

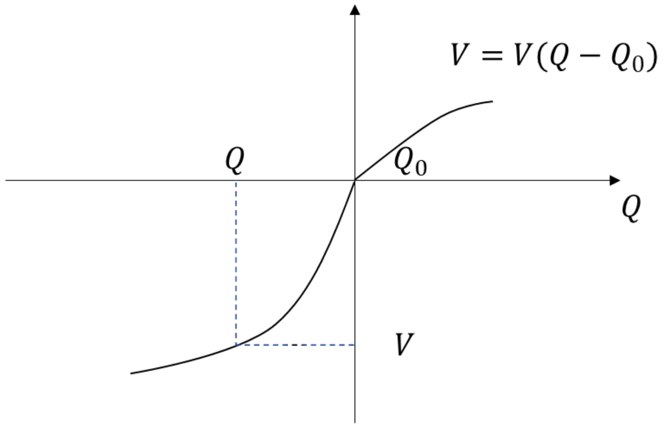


Figure 3: Value function

We then derived the valuation function for each section. For Section 1: $V_1 = V(Q^b - Q_1)$; for Section 2: $V_2 = V(Q^b - Q_2)$; for Section 3, $V_3 = V(Q^a - Q_3)$; and for Section 4, $V_4 = V(Q^a - Q_4)$, where Q^b refers to the air quality before the start of the heating season and Q^a refers to the air quality after the start of the heating season. The air quality before the heating season was better than the air quality after the heating season started, so we have $Q^a < Q^b$. Q_i is the reference point for each section. We have arranged the value functions for each section in Table 2:

Table 2: Valuation function matrix

	Without extra health damage information	With extra health damage information
Before the heating season starts	$WTP^1/WTA^1 = \|V_1\| = \|V(Q^b - Q_1)\|$	$WTP^2/WTA^2 = \|V_2\| = \|V(Q^b - Q_2)\|$
After the heating season starts	$WTP^3/WTA^3 = \|V_3\| = \|V(Q^a - Q_3)\|$	$WTP^4/WTA^4 = \|V_4\| = \|V(Q^a - Q_4)\|$

3.4 Hypotheses testing

In considering the experience of heavy air pollution, the reference points adaptation should be one of the following three cases: no adaptation, partial adaptation, and full adaptation. Take the buyers in Sections 1 and 3 as an example.

In the case of no adaptation, the reference point remained the same as when the air quality was good, i.e., $Q_3 = Q_1$. As the air quality deteriorated, $Q^a < Q^b$, and then we had $|V_3| > |V_1|$, and $WTP^3 > WTP^1$. Since people felt worse about air pollution, they were prepared to pay more for the PM 2.5 filters, as shown in Figure 4 (a).

For the case of a partial adaptation, the reference point adjusted downwards by less than the air quality decreased, i.e., $Q_1 - Q_3 < Q^b - Q^a$, and thus we had $Q^a - Q_3 < Q^b - Q_1$, so that $|V_3| > |V_1|$ and $WTP^3 > WTP^1$. People were prepared to pay more for the PM 2.5 filters as they felt worse about the deterioration in air quality, as shown in Figure 4 (b).

In the case of a full adaptation, the reference points adjusted downwards by as much as the air quality deteriorated so that people did not feel there was any difference, i.e., $Q_1 - Q_3 = Q^b - Q^a$, so that $V_3 = V_1$ and $WTP^3 = WTP^1$. This case is depicted in Figure 4 (c).

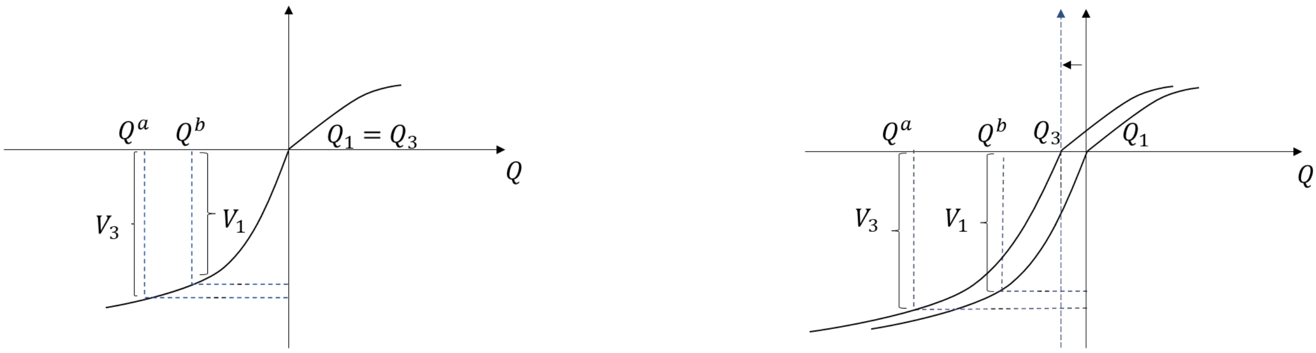
Therefore, to test Hypothesis 1 that people would fully update their reference points after seven weeks of bad air quality, we needed to compare the biddings for Sections 1 and 3. If $WTP^3 = WTP^1$, we can thus infer that there is a full adaptation; otherwise, there would either be a partial adaptation or no adaptation.

We also tested H1 by comparing Section 2 with Section 4. Likewise, if $WTP^2 = WTP^4$, then we have a full adaptation of the reference point; otherwise, there is a partial adaptation or no adaptation.

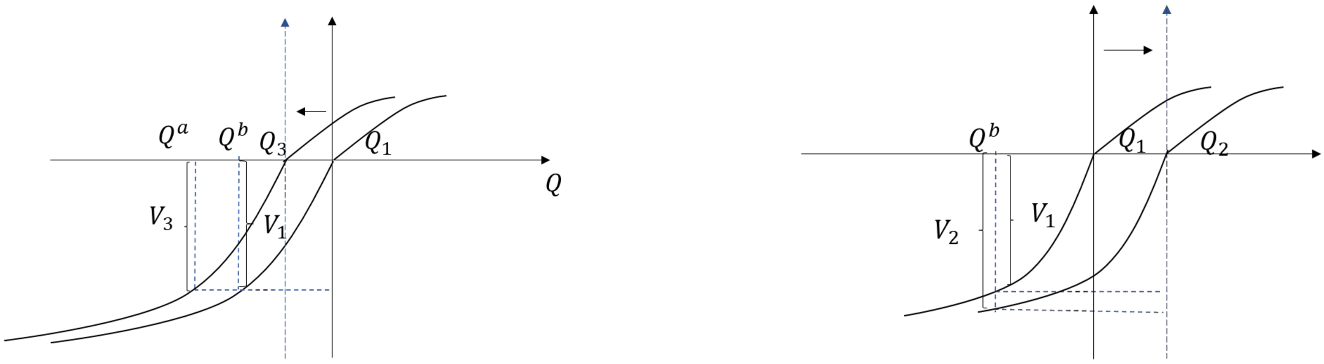
To test Hypothesis 2 that the extra information on the relationship between death rates and air pollution causes people to adjust their reference points upwards, we compared Section 1 and Section 2. As shown in Figure 4 (d), if the information drives the reference point upwards, then $Q_2 > Q_1$, and we will have $|V_2| > |V_1|$ and $WTP^2 > WTP^1$. People were found to be willing to pay more for the PM 2.5 filters as the information made them feel worse about the same amount of air pollution. If the extra information does not affect the reference point formation, then we will have $Q_2 = Q_1$, $V_2 = V_1$, and $WTP^2 = WTP^1$.

We also tested H2 by comparing Section 3 with Section 4. If $WTP^4 > WTP^3$, we will have $Q_4 > Q_3$ and the reference points will adjust upwards; otherwise, we will have $WTP^4 = WTP^3$ and $Q_4 = Q_3$.

H1 and H2 can also be tested on the sellers' side using the WTA approach.



(a) No adaptation, $Q_1 = Q_3$, $|V_3| > |V_1|$ (b): Partial adaptation, $Q_1 - Q_3 < Q^b - Q^a$, $|V_3| > |V_1|$



(c): Full adaptation, $Q_1 - Q_3 = Q^b - Q^a$, $|V_3| = |V_1|$ (d): Reference point adjust upward, $Q_2 > Q_1$, $|V_2| > |V_1|$

Figure 4: Reference points adjustments

4. Results and discussion

4.1 Testing Hypothesis 1 from the buyers' side: full adaptation to the status quo

We tested Hypothesis 1 by comparing Section 1 and Section 3, without extra health damage information, and by comparing Section 2 and Section 4, with extra health damage information. The WTP values of these sections are summarized in Table 3.

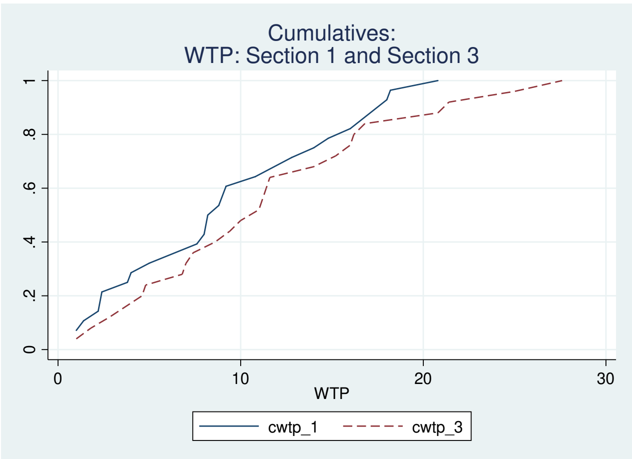
As can be seen in Table 3, both the mean and median bidding values for buyers in Section 1 are smaller than those in Section 3. The cumulative distribution functions (CDFs) of Section 1 and Section 3 are depicted in Figure 5 (a). The CDF of Section 3 is to the right of the CDF of Section 1. Since Section 1 and Section 3 are independent samples with different numbers of observations (unmatched data), we applied the Wilcoxon rank-sum test to test whether the differences between these two sections were significant. The null hypothesis of $WTP^1 = WTP^3$ could not be rejected at the p-value of 0.34. The differences in terms of the WTP values between Section 1 and Section 3 were not significant. Thus, in accordance with the case pictured in Figure 4 (c), we have $Q_1 - Q_3 = Q^b - Q^a$, a full adaptation.

Table 3: Bidding prices of the buyers in the four sections

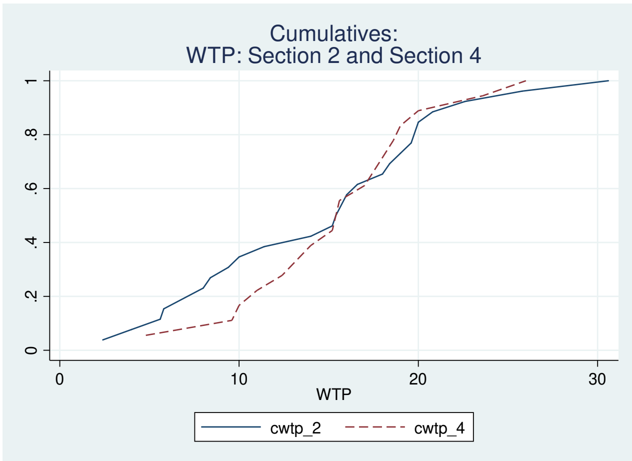
Percentile	WTP_1	WTP_2	WTP_3	WTP_4
Mean	9.44	14.65	11.48	15.71
Median	8.5	15.7	11	15.6
Observations	28	26	25	18

As can be seen in Table 3, the mean value of the WTPs for Section 4 is 15.71, a little higher than that of Section 2, or 14.65, but the median for Section 4 is lower than that of Section 2. A comparison between Section 2 and Section 4 is depicted in Figure 5 (b). As we can see, the cumulative distribution function (CDF) for Section 2 is well mixed with the CDF for Section 4. It is thus hard to tell the difference between these two sections. Besides, the Wilcoxon rank-sum test fails to reject the null hypothesis $WTP^2 = WTP^4$ with a p-value of 0.63.

Thus, both the comparison between Sections 1 and 3 and the comparison between Sections 2 and 4 suggest that seven weeks of heavy air pollution has not significantly changed the subjects' willingness to pay for the PM 2.5 filters. Hypothesis 1 is thus supported[3]. People were found to adjust their reference points on air pollution downwards as the air quality deteriorated. Moreover, people fully adapted themselves to the heavily polluted air.



(a) Sections 1 and 3



(b) Sections 2 and 4

Figure 5: The CDFs of the WTP values of the four sections used to test Hypothesis 1.

[3] We also checked the subjects' mask purchasing plan for this heating season for each of the four sections. The results show that subjects in Section 3 and Section 4 exhibited higher propensities (73% and 74%, respectively) to buy a mask than did subjects in Section 1 and Section 2 (47% and 55%, respectively). This finding ruled out the possibility that individuals in Section 3 and Section 4 purchased masks and thus would not pay more in this experiment.

4.2 Testing Hypothesis 2 from the buyers' side: extra health damage information

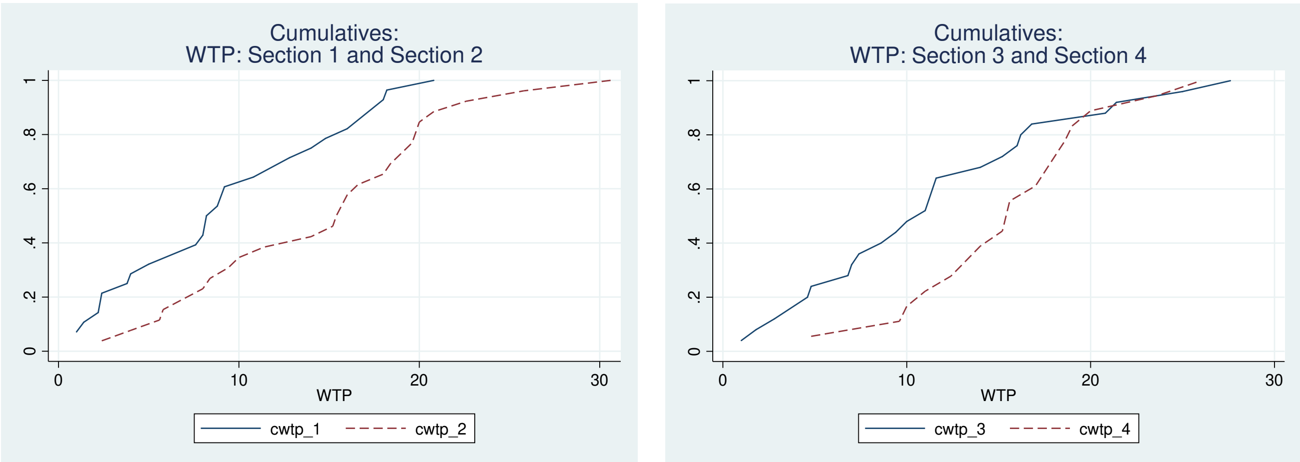
In Section 3 and Section 4, we gave students extra information on the relationship between the death rates and the concentration of particulate matter, i.e., PM 2.5. We also showed students the standard for a safe yearly average PM 2.5 concentration level recommended by WHO, together with the current standards adopted by China and some developed countries. The information is shown in Appendix 2.

Similarly, we tested Hypothesis 2 by both comparing Section 1 with Section 2 and by comparing Section 3 with Section 4.

As shown in Table 3, the mean WTP value of Section 2 is 14.65, which is about 55.2% higher than the mean WTP for Section 1. The median value of WTP in Section 2 is 15.7, about twice the value of that in Section 1. Besides, the CDF for Section 2 lies far to the right of that for Section 1, as shown in Figure 6 (a). According to the value function, $WTP^1 < WTP^2$, and we thus have $Q_2 > Q_1$. The new information helped people adjust their reference points on air quality upwards. The Wilcoxon rank-sum test rejects the null hypothesis with a p-value of 0.0059, suggesting that there is a significant difference in the WTPs between the two sections.

Similarly, both the mean and median values of the WTPs for Section 4 are larger than those for Section 3. Figure 6 (b) shows that, except for the upper end of the distribution, the CDF curve for Section 4 is always to the right of the CDF curve for Section 3. Since $\mathrm{WTP}_3 < \mathrm{WTP}_4$, we have $Q_4 > Q_3$. The null hypothesis is rejected with a p-value of 0.0258 in the Wilcoxon rank-sum test, suggesting that there has been a significant upward adjustment of the reference points following the receipt of the new damage information.

Hypothesis 2 is thus supported, indicating that extra information on the relationship between the death rates and air pollution did cause people to feel worse about the current air pollution and to adjust their reference points upwards.



(a) Sections 1 and 2 (b) Sections 3 and 4

Figure 6: The CDFs of the WTP values for the four sections used to test Hypothesis 2.

4.3 Testing Hypotheses 1 and 2 from the sellers' side: the WTA approach.

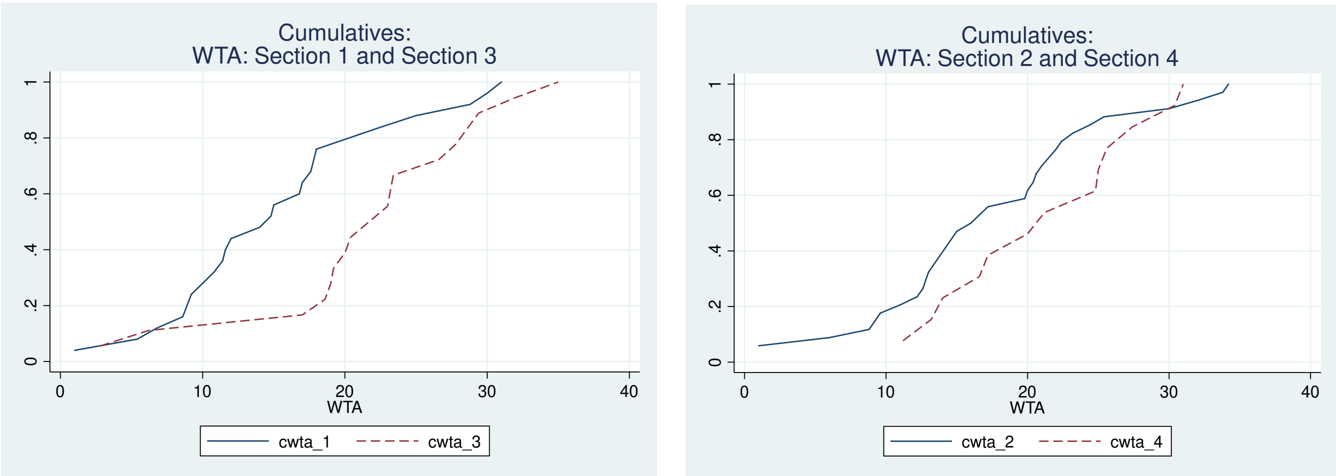
The other approach used to test Hypothesis 1 and Hypothesis 2 was to adopt the WTA approach, i.e., to employ the bidding values of the sellers instead of those of the buyers.

Table 4: Bidding prices of the sellers for the four sections

	WTA_1	WTA_2	WTA_3	WTA_4
Mean	15.49	17.35	21.96	21.36
Median	14.8	16.3	23	21.2
Observations	25	34	18	13

First of all, for Section 1 and Section 3, it can be seen that both the mean and median values of the WTA for Section 3 are larger than those for Section 1, which is obvious when one looks at Table 4 and Figure 7 (a). The CDF of the WTA values in Section 3 lies to the far right of the CDF of the WTA values in Section 1. The Wilcoxon rank-sum test exhibits a significant difference between the two sections with a p-value of 0.006. A comparison of Section 2 and Section 4 reveals a similar result. The CDF of the WTA values for Section 4 lies to the right of that for Section 2, as shown in Figure 7 (b). The Wilcoxon rank-sum test confirms the significance of the difference between the two sections with a p-value of 0.094.

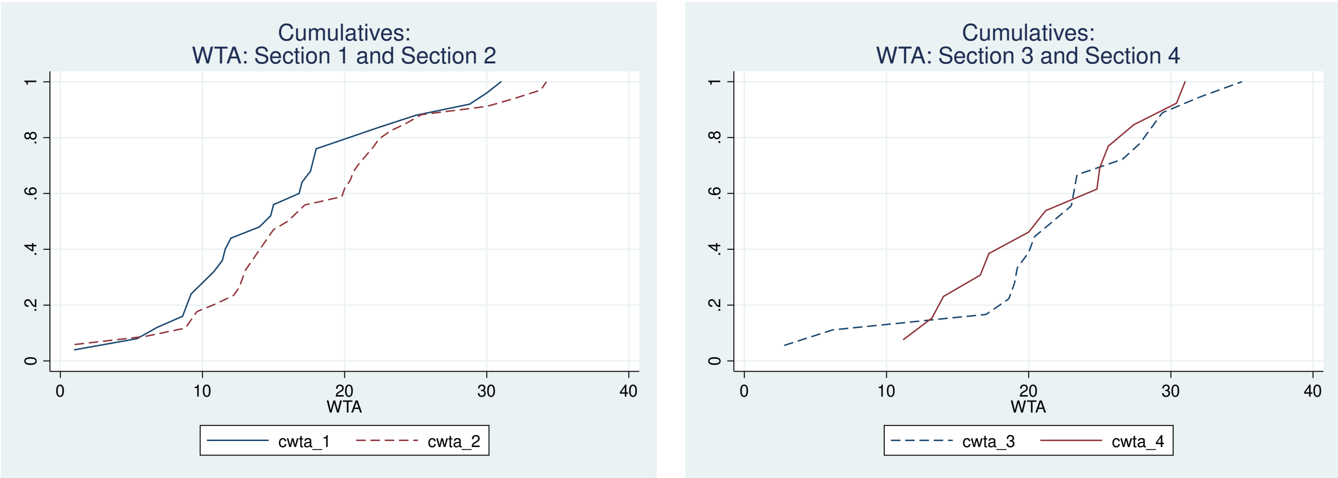
In testing Hypothesis 1, our findings from the sellers' side suggest either partial adaptation or no adaptation at all. The findings from the sellers' side are different from our findings from the buyers' side, where there is a full adaptation of the reference point. Sellers exhibit a slower adaptation to the deterioration of air quality than buyers.



(a) Sections 1 and 3 (b) Sections 2 and 4

Figure 7: The CDFs of the WTA values of the four sections used to test Hypothesis 1.

Similarly, in testing Hypothesis 2, the WTA approach also leads to findings that differ from those for the WTP approach. As shown in Table 5 and Figure 8, the WTA values in Section 1 and Section 2 are close to each other, as are the WTA values in Section 3 and Section 4. The Wilcoxon rank-sum test fails to reject the null hypothesis in both cases, with p-values of 0.322 and 0.674, respectively. This suggests that the extra information on the relationship between the death rates and air pollution does not significantly change the reference points of sellers. The sellers are more reluctant to adjust their reference point upwards upon the receipt of extra health damage information than are buyers.



(a) Sections 1 and 2 (b) Sections 3 and 4

Figure 8: The CDFs of the WTA values of the four sections used to test Hypothesis 2.

4.4 Asymmetric adaptation.

To further explore the differences between the WTA and WTP in these sections, we calculated the ratio of WTA to WTP with both the mean and median values for each section and rearranged them as shown in Table 5 below.

Table 5: The mean (median) value of the WTA/WTP ratio

	Without extra health damage information	With extra health damage information
Before the heating season starts	1.64 (1.74)	1.18 (1.04)
After the heating season starts	1.91 (2.09)	1.36 (1.36)

There are some interesting findings in Table 5. The WTA/WTP ratio becomes larger as the air quality gets worse. The worse air quality raises sellers' bids more than the buyers' bids. The higher biddings of sellers suggest that, unlike the buyers' full adaptation, the sellers' reference points adjust less as the air quality worsens.

At the same time, the WTA/WTP ratio decreases upon receipt of the extra information. The knowledge regarding the relationship between death rates and air pollution affects buyers more than sellers. Sellers adjust their reference points less upon receiving the extra health damage information than the buyers.

The findings suggest that asymmetry exists in the adaptation of reference points for buyers and sellers. Sellers are less flexible in adjusting their reference points on air quality than are buyers.

According to prospect theory (Kahneman and Tversky, 1979), the value function in the gain domain is concave, denoting a decreasing marginal utility of per unit consumption. However, in the loss domain, the value function is convex, referring to an increasing marginal return of each unit of consumption. In the gain domain, the first unit of gain brings more utility than the second unit of gain, and thus an individual will find it beneficial to increase the reference point right after a gain. By contrast, in the loss domain, the second unit of loss is less painful than the first unit of loss, and so a rational individual will tend not to adjust the reference point upon experiencing a loss. Thus, the reference point tends to adapt faster after a gain than a loss. The asymmetry in reference point adaptation after gains and losses is the right choice under hedonic maximization.

In our experiment, we gave the sellers four PM 2.5 filters free of charge. After providing an introduction to the basic health damage caused by air pollution and explaining the BDM procedure, we asked them to sell the four PM 2.5 filters. To them, selling the filters makes them feel less protected from air pollution and thus seems like a loss. As for the buyers, buying the filters makes them feel less threatened by air pollution, which could be perceived as a gain. Thus, it is reasonable for the reference point on air quality to adjust faster upon gains (among buyers) than upon losses (among sellers).

The asymmetric adaptation in gains and losses is not just a theoretical finding but is verified both in everyday life and in experimental studies. For example, the "ratchet effect" in consumption describes the phenomenon that adaptation to higher consumption (a gain) is always easier than adaptation to lower consumption (a loss). Another example is that people tend to attribute success (a gain) to their efforts and accept it readily, while they tend to regard failure (a loss) as bad luck and refuse to accept it.

Arkes et al. (2008) found evidence of persistent faster adaptation after gains than after losses among US subjects using both a survey (without a monetary incentive) and the BDM procedure (with a monetary incentive). They also found that asymmetric adaptation is helpful in explaining many findings in earlier studies, for example, sunk cost effect can also be explained by people unwilling to adapt to past losses (Arkes and Blumer, 1985); 'hedonic treadmill' (Brickman, Coates, and Janoff-Bluman, 1978), that people adapt fast to gains that the past improvements quickly become insufficient, can also be explained by people's fast adaptation to gains; the asymmetric adaptation to losses and gains can also help explain the disposition effect in stock trading, that people hold losers too long and sell winners too fast (Gneezy, 2005). Arkes et al. (2010) extended their study to a cross-cultural study including China, Korea, and the United States. They found that adaptation after a gain took place more quickly than after a loss of equal magnitude in all countries. Bernasconi et al. (2014) examined the effect of the tax burden on tax evasion both theoretically and experimentally. In their experiment, they observed that subjects adapted faster to a tax cut than to an increase in the tax rate.

Our findings support those of Arkes et al. (2008; 2010) and Bernasconi et al. (2014) in regard to the asymmetry in adaptation and extend the findings to the field of environmental goods.

4.5 Robustness check.

In this experiment, we collected data on the personal characteristics that have a potential effect on the bidding values of the respondents, such as gender, age, whether he/she is a graduate or undergraduate student, his/her BMI, whether he/she smokes, the experiences of using facemasks, the purchase plan regarding the facemasks, and some information regarding healthy daily habits. The summary statistics of the variables are provided in Appendix 4. The regression results are presented in Table 6. Columns 1 and 2 are the results without controlling for the *maskplan* (the purchase plan for facemasks for this heating season). Columns 3 and 4 are the results controlling for the *maskplan.* Since none of these personal characteristics and habits exhibit a significant influence on the biddings, the coefficients of these factors are not shown. The findings prove the robustness of our findings regarding the adaptation of the reference points in relation to air quality in three ways.

First of all, the insignificant coefficients for all the personal traits relaxed the random sampling constraint in this experiment. According to the design of our experiment, we relied on the changes in the bidding values to infer the changes in the reference point. Only on the basis of random sampling could the changes in the bidding values among different sections be interpreted as the changes in the reference points. The regression results showed that none of the personal traits that we could think of had a significant influence on the biddings of either buyers or sellers. This helped relax the constraint attached to random sampling in this experiment and made our findings more robust.

Secondly, columns 1 and 3 show that in the regression with WTP as the dependent variable, the only significant influence came from the treatment with extra health damage information. Buyers improved their reference points on air quality as the new information made them feel worse about the current level of pollution. The insignificant coefficient for *after* confirmed the findings in Sections 4.1 and 4.2 that people fully adapted to worse pollution after being exposed to seven weeks of heavy pollution. When we further control for the *maskplan* in column 3, the results do not change much from those in column 1. Our findings with buyers hold no matter they have a mask purchase plan or not.

Similarly, in columns 2 and 4, the insignificant coefficient of *withinf* denotes that for sellers, the extra information regarding health damage did not help them migrate to higher reference points. Besides, the positive and significant coefficient of *after* in column 2 suggests that the experience of seven weeks of heavy pollution makes sellers bid more, confirming our findings in 4.3. Moreover, in column 4, when the *maskplan* is controlled, the coefficient of *after* becomes insignificant. It suggests that the experience of seven weeks of heavy pollution makes sellers bid more by increasing the demand for the anti-PM 2.5 facemasks.

Third, in column 4, the coefficient of *maskplan*, the plan to purchase a facemask for this heating season, was both positive and significant, suggesting that people who had such purchase plans asked for 5 yuan more for their PM 2.5 filters to be taken away. This could serve as further proof for our findings regarding the reluctance of sellers to adapt. We have argued that asking the sellers to give away the PM 2.5 filters which they had been given free of charge is painful. The loss of the actual things they needed placed them in the domain of loss, and thus they were less prepared to adjust their reference points.

Table 7: Regressions with WTP and WTA values

	(1) WTP	(2) WTA	(3) WTP	(4) WTA
after	2.405	5.230^{*}	2.305	3.906
	(1.64)	(2.41)	(1.56)	(1.79)
withinf	4.316^{**}	0.104	4.193^{**}	0.559
	(2.91)	(0.05)	(2.78)	(0.29)
maskplan			0.941	5.001^{*}
			(0.57)	(2.33)
Other factors	yes	yes	yes	yes
Observations	95	89	95	89
Adjusted R^2	0.056	-0.010	0.047	0.050

t statistics are in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We also considered the demand increase for facemasks in winter and the corresponding price increase. In the first two sections of our experiment, the anti-PM 2.5 facemasks we bought were 25 yuan each. In the latter two sections, the price increased to 27 yuan. Though we don't know the price of the filters, it is safe to infer that the price of the filters has increased less than 2 yuan. Columns 1 and 3 show that buyers on average are willing to pay about 2.3 yuan more after seven weeks of heavy pollution. However, the difference is not significant. Our findings of buyers' full adaptation to heavy pollution are not affected. Column 2 suggests that sellers ask for 5 yuan more for giving up their filters after seven weeks of heavy pollution. This is much higher than the possible filter price increase. Even after we control the *maskplan*, average sellers still ask for 4 yuan more. The price increase for filters does not affect our findings of the adaptation upon new health damage information.

5. Conclusion

In this paper, we have explored the adaptation of reference points in relation to air quality using an exquisitely designed lab experiment based upon two treatments: the experience of seven weeks of heavy air pollution, and the receipt of extra information on the relationship between death rates and air pollution. The subjects in this experiment were asked to trade four PM 2.5 filters with monetary incentives using the BDM procedure. We showed that for buyers, being exposed to heavy pollution for seven weeks drove them to fully adapt to the worse air quality, with the result that their reference points decreased by as much as the deterioration in air quality. Besides, the extra health damage information caused them to adjust their reference points upwards towards better air quality. For sellers, the seven weeks of poorer air quality increased their bidding prices for the PM 2.5 filters, suggesting that the reference points adaptation was not a full adaptation, while the provision of extra information did not increase their reference points at all.

This paper, as far as we know, is the first to explore the adaptation of reference points in relation to environmental goods and adds to the literature on asymmetric reference points adaptation. This paper has important implications for the valuation of non-market goods, where the reference point matters. Furthermore, the asymmetry in reference points adaptation has made the valuation of environmental goods more challenging as most of the property rights in relation to the environmental goods are not clearly defined.

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Appendix 1

Introduction (for buyers; the introduction for sellers is similar)

Welcome to this anonymous economic experiment on air pollution. The experiment will last about 30 minutes. Your payment in this experiment will consist of two parts: a fixed fee of 20 yuan, and the earnings you receive in the BDM auction.

This experiment consists of three parts: a brief review of the basic damage to health caused by air pollution, two hypothetical trials, and five rounds of real experiments. After the experiment, you will be asked to answer a simple survey.

We will randomly choose one of the five rounds as the final round, and what you earn in that round will be your earnings from the experiment. Notice that you may have a negative income!

You are not allowed to communicate with others during this experiment.

Part 1:

Basic information on damage to health caused by air pollution

Physical aspect:

Long-term (a year and above) exposure and short-term (several weeks) exposure to air pollution can cause cardiovascular diseases (including high blood pressure, heart disease, cerebrovascular disease, strokes, etc.), respiratory diseases, and asthma, etc. It can also damage lung function and cause lung cancer.

Cognitive aspect:

Fine particles will damage the brain function either by directly entering the brain or by causing inflammation of the central nervous system. They will also reduce the cognitive ability of humans.

Psychological aspect:

Living in polluted air will cause depression and a decrease in life satisfaction.

Part 2: Hypothetical trial:

You are a buyer and you are going to buy a token from the instructor. The value of the token is T yuan. The value of the token varies for different subjects and is within the range of 1-15.

Now you are buying this token from the instructor. Please write down your highest bidding price for this token (B). After you make your decision, we will randomly draw a number between 1 and 15 as the market price (P).

If your bidding price is higher or equal to the market price ($B \geq P$), then a trade will take place, and you will buy this token at the market price. Otherwise, the trade will not take place, and you will not get this token and will not need to pay anything.

Please note:

(1) Your decision does not affect the market price as it is randomly chosen.

(2) Revealing your true preference is best for you, as bidding too low or too high may result in losses.

An example:

Assume the value of the token is 6 yuan. If your bidding price is 8 yuan and the market price is 7 yuan, then the trade will take place, and you will buy the token for 7 yuan, losing 1 yuan. Thus, bidding too high is not to your benefit. Similarly, if your bidding price is 4 yuan and the market price is 5 yuan, then the trade cannot take place, and you will lose the chance to buy the token at 5 yuan, also losing 1 yuan. Thus, bidding too low is also bad for you.

After the trade, please calculate the earnings in this trial:

$$Earnings = \begin{cases} T - P, & if \text{ the trade takes place} \\ 0, & \text{otherwise} \end{cases}$$

Quiz:

1. If my bidding price B is higher than the market price P, then the trade will take place.
   ☐ True ☐ False

2. If I buy this token, and the value of this token T is higher than the market price P, then I will have positive earnings.
   ☐ True ☐ False

Round 1:

In this round, the value of your token T =________ yuan. (Instructors will give some random numbers between 1 and 15)

Your bidding price B=________ yuan. (B should be within 1-15 yuan)

The market price P=________ yuan, and your earnings in this round is ________ yuan.

Round 2:

In this round, the value of your token T =________ yuan. (Instructors will give some random numbers between 1 and 15)

Your bidding price B=________ yuan. (B should be within 1-15 yuan)

The market price P=________ yuan, and your earnings in this round is ________ yuan.

Part 3:

Real trials.

The procedures in the real trials are the same as in the hypothetical trials, but the goods traded are the four PM 2.5 filters, rather than a token.

(The instructors now give every subject an anti-PM 2.5 facemask that consists of one normal mask and four PM 2.5 filters)

Brief introduction to the anti-PM 2.5 facemasks:

The anti-PM 2.5 facemasks are produced by Shanghai Xingnuo Kanglun Fiber Technology Co., Ltd. The facemask has *three layers, and the middle layer is a replaceable filter that can effectively filter the fine particles and bacteria in the air. The filters were tested in the NELSON laboratory in the US and were found to have filtered more than 99% of the PM 2.5 in the air. Usually, one PM 2.5 filter can last for a week. There are four PM 2.5 filters in the package beside one normal mask.*

(Then the instructors will ask the buyers to give back the four filters and keep only the normal mask, while the sellers can keep both the four filters and the normal mask)

You are a buyer. Now that you have a normal mask, how much would you like to pay for the four PM 2.5 filters to upgrade your mask to an anti-PM 2.5 mask (the biddings should be between 1 and 40)? Please write your bidding down on the dashed line. After you make your decision, we will randomly draw a price between 1 and 40 as the market price.

If your bidding price is higher than or equal to the market price, then a trade will take place, and you will buy four PM 2.5 filters at the market price. Otherwise, the trade cannot take place, and you will not receive the four PM 2.5 filters or need to pay anything.

Please note:

(1) Your decision does not affect the market price as it is randomly chosen.

(2) Revealing your true preference is best for you, bidding too low or too high may result in losses.

We will run five rounds of real trials, where each round is independent of the others. After all five runs are completed, we will randomly choose one as the final result and trade with you using real money.

Quiz:

3. If my bidding price for the four PM 2.5 filters is higher than the market price, then the trade will take place.
   ☐ True ☐ False

Now we need you to evaluate the air quality in your area today:
☐ Very bad ☐ Bad ☐ Normal ☐ Good ☐ Very good

Round 1:

Your bidding price for the four PM 2.5 filters is ________ yuan. (bids should be within 1-40 yuan)
The market price P=________ yuan.
Does the trade take place in this round? ________ (Yes/No)

Round 2:

Your bidding price for the four PM 2.5 filters is ________ yuan. (bids should be within 1-40 yuan)
The market price P=________ yuan.
Does the trade take place in this round? ________ (Yes/No)

Round 3:

Your bidding price for the four PM 2.5 filters is ________ yuan. (bids should be within 1-40 yuan)
The market price P=________ yuan.
Does the trade take place in this round? ________ (Yes/No)

Round 4:

Your bidding price for the four PM 2.5 filters is ________ yuan. (bids should be within 1-40 yuan)
The market price P=________ yuan.
Does the trade take place in this round? ________ (Yes/No)

Round 5:

Your bidding price for the four PM 2.5 filters is ________ yuan. (bids should be within 1-40 yuan)
The market price P=________ yuan.
Does the trade take place in this round? ________ (Yes/No)

Round________ is randomly chosen; your bidding price in this round is________ yuan

Appendix 2

WHO Air quality guidelines for particulate matter
Global update 2005

Table 1: WHO air quality guidelines and interim targets for PM 2.5: Annual mean concentrations

	PM 2.5 （$\mu g/m^3$）	**The basis for the selected level**
Interim target-1 (IT-1)	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to the IT-1 level.
Interim target-3 (IT-3)	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the IT-2 level.
Air quality guideline (AQG)	**10**	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM 2.5.

Table 2: WHO air quality guidelines and interim targets for PM 2.5: 24-hour concentrations

	PM 2.5 （$\mu g/m^3$）	**The basis for the selected level**
Interim target-1 (IT-1)	75	Based on published risk coefficients from multi-city studies and meta-analyses (about a 5% increase in short-term mortality over the AQG value).
Interim target-2 (IT-2)	50	Based on published risk coefficients from multi-city studies and meta-analyses (about a 2.5% increase in short-term mortality over the AQG value).
Interim target-3 (IT-3)	37.5	Based on published risk coefficients from multi-city studies and meta-analyses (about a 1.2% increase in short-term mortality over the AQG value).
Air quality guideline (AQG)	**25**	Based on the relationship between 24-hour and annual PM levels.

Table 3：The guidelines adopted for PM 2.5 concentrations in some countries (regions):

Country (region)	Annual concentrations ($\mu g/m^3$)	24-hour concentrations ($\mu g/m^3$)
US	12	35
Japan	15	35
Europe	20	
Taiwan	15	35
Australia	8	20
China	**35**	**75**

Appendix 3

Survey

1. Gender ☐ Male ☐ Female
2. Birth year: _________
3. Height: __________cm, weight: ___________kg
4. Education
   ☐ Undergraduate ☐ Graduate
5. Major: ________________________
6. Do you have student insurance?
   ☐ Yes ☐ No
7. Do you have other commercial insurance?
   ☐ Yes ☐ No
8. The income per capita in your family (yuan)
   ☐ 1000 and bellow ☐ 1000-2000 ☐ 2000-3000 ☐ 3000-4000
   ☐ 4000-5000 ☐ 5000-6000 ☐ 6000-7000 ☐ 6000-7000
   ☐ 7000-8000 ☐ 8000-10000 ☐ 10000 and above
9. The main city you resided in 2017?
10. The air quality of that city is
    ☐ Very bad ☐ Bad ☐ Normal ☐ Good ☐ Very good
11. Do you smoke?
    ☐ Yes, about ___________cigarette(s) every day ☐ No
12. How often do you eat vegetables and fruits as part of your diet?
    ☐ Not at all ☐ 1-3 times a month ☐ 1-3 times a week
    ☐ Every day
13. Do you have nutritional supplements?
    ☐ No
    ☐ Yes (including vitamins, calcium, fish oil)
    ☐ Yes (others)
14. Do you usually go to bed before 11 pm? ☐ Yes ☐ No
15. How often do you workout?
    ☐ Not at all ☐ Rarely
    ☐ Not every day, less than 3 hours a week
    ☐ Not every day, more than 3 hours a week
    ☐ Every day, less than 3 hours a week
    ☐ Every day, more than 3 hours a week
16. Do you have a health examination every year?
    ☐ Yes ☐ No
17. Have you ever bought anti-haze facemasks for yourself?
    ☐ Yes ☐ No
18. Have you ever bought anti-haze facemasks for your family or friends?
    ☐ Yes ☐ No
19. Are you planning to buy anti-haze facemasks this year?
    ☐ Yes ☐ No
20. How often did you use anti-haze facemasks in the last heating season (November 2017-March 2018)
    ☐ Almost never ☐ Occasionally ☐ Sometimes ☐ Most of the time ☐ Every day
21. In addition to the anti-haze mask, what other protective measures do you adopt to protect yourself in the

haze?

- ☐ None
- ☐ Yes. Other protective measures include ________________

Appendix 4

Table 3: Summary Statistics

Variable	Definition	Obs.	Mean	Std. Dev.	Min	Max
wtp	bidding price of buyers	97	12.53	6.83	1	30.6
wta	bidding price of sellers	90	18.33	8.15	1	35
female	dummy, 1 if female	187	0.42	0.49	0	1
bmi	body mass index. (Kg/m^2)	186	21.44	3.69	7.17	45.75
grad	dummy, 1 if graduate student	187	0.34	0.48	0	1
stuinsurance	dummy, 1 if answer to question 6 is 'yes'	187	0.79	0.41	0	1
cominsurance	dummy, 1 if answer to question 7 is 'yes'	187	0.44	0.50	0	1
rich	dummy, 1 if income per capita is more than 6000 yuan	186	0.20	0.40	0	1
goodaq	dummy, 1 if answer to question 10 is 'good' or 'very good'	187	0.24	0.43	0	1
smoke	dummy, 1 if answer to question 11 is 'yes'	187	0.14	1.48	0	20
lvege	dummy, 1 if answer to question 12 is 'not at all' or '1-3 times a month'	187	0.05	0.23	0	1
ntrsupm	dummy, 1 if answer to question 13 is 'yes'	187	0.34	0.48	0	1
slpbf11	dummy, 1 if answer to question 14 is 'yes'	186	1.72	0.45	1	2
dmworkout	dummy, 1 if answer to question 15 is 'every day'	187	.096	0.30	0	1
medicaltests	dummy, 1 if answer to question 16 is 'yes'	187	0.20	0.40	0	1
maskexp	dummy, 1 if answer to question 17 is 'yes'	187	0.72	0.96	0	12
maskplan	dummy, 1 if answer to question 19 is 'yes'	186	0.60	0.49	0	1
dmmaskfrq	dummy, 1 if answer to question 20 is 'most of the time' or 'everyday'	187	0.18	0.39	0	1
antihaze	dummy, 1 if answer to question 21 is 'yes'	186	0.31	0.46	0	1
after	dummy, 1 if after start of heating season	187	0.40	0.49	0	1
withinf	dummy, 1 if with the extra health damage information	187	0.49	0.50	0	1