Exploring the effect of stepwise-multiple-round bidding on willingness-to-pay in contingent valuation study–When can we trust respondents' preferences

By

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ABSTRACT

The contingent valuation method (CVM) has been widely used by economists and statisticians to measure the benefits of non-market goods or services since the 1990s. The framework for CVM is derived from the utility function of welfare economics. CVM asks people directly about their willingness to pay (WTP) for the value of specific goods or services, or willingness to accept to give up the value of goods or services.

China has achieved rapid economic growth over the past three decades, during this period, however, it also faced serious environmental challenges and problems, for example, air pollution. China and the United States are jointly responsible for 40% of the world's carbon emissions. This thesis analyses people's concerns about environmental issues using CVM. Specifically, we implement the classical maximum likelihood estimation (MLE) method and the Monte Carlo Markov Chain (MCMC) simulation-based method to evaluate people's willingness to pay (WTP) for the improvement of environmental quality via support of a "geo-engineering" project.

The data used in this thesis was collected through face-to-face interviewing in four cities in China, Harbin (northeast and inland), Zhengzhou (north and in-

land), Changsha (central-south and inland) and Zhuhai (southeast and coastal). We interviewed 1,044 participants, asked them to answer a CVM survey questionnaire and collected their responses. The CVM questionnaire included six aspects of information that could affect respondents' WTP. In addition to the social-demographics related to the respondents' preferences, e.g. gender, age, household income, we also asked about respondents' health conditions, social connections and awareness of political issues, governmental support and risks of human activities on environment and etc. Using this sample, we initially employed the step-wise and logistic regression models to identify the significant factors, then we applied the classical MLE to model the single- and double-bounded CVM answers and the WTP values, and expanded the modelling procedures to multiple-rounds bidding processes. Further more we also used MCMC to analyse the mean WTP values through multiple rounds of bidding process.

MLE results suggested that the fitted mean WTP values from single-, double- and triple-bounded MLE models were CNY816.56, CNY565.79 and CNY539.27, respectively. The gap between the single- and the double-bounded estimates showed that the WTP estimates from commonly-used single-bounded approach could lead to unreliable results. We also discovered that the more respondents believed that they gained benefit from the "geo-engineering" project, the more they were willing to agree to the given bid, and were likely to pay a greater price; the more respondents were prepared to spend on pollution reduction products, the equated to their awareness of the harm of pollution, the more they would like to pay. Results also supported that being admitted to hospital was positively related to the value of WTP; being interested in news and public affairs had a negative effect on mean WTP. On the other hand, the estimated mean WTP values from the MCMC approach for the single, double and triple-bounded models were CNY810.82, CNY566.10 and CNY510.22, respectively, largely consistent with the results in MLE. MCMC improved WTP models because it produced more significant variables and narrower confidence intervals.

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Introduction to Policy Valuation Using Surveys

1.1 Introduction and Background

Surveys are widely used as a method of gathering information about personal characteristics and on a variety of topics. Surveys can provide essential information and provide insights into the analysis of problems in a wide range of areas, for example, in economics, business, social sciences, and healthcare. There are several types of survey and the applications vary from field to field. This thesis uses the survey data from face-to-face interviews to gather information and evaluate how much people would be willing to pay for the improvement of environmental quality via an increase in their annual income tax. This is the application of the stated preference technique to survey for non-market product using the contingent valuation method (CVM).

1.1.1 Climate Change

Climate change poses a severe threat to people's survival in both developed and developing countries, according to mounting observational and experimental evidence (Berry et al., 2018; World Health Organization, 2014; K. Smith et al., 2014; Horton et al., 2014; Hoegh-Guldberg et al., 2018). The growing scientific evidence clearly demonstrates that climate change impacts both humanity and nature, including the natural ecosystem (Hoegh-Guldberg et al., 2018).

The Earth's climate system is influenced by climate forcings, including natural phenomena and anthropogenic activities (Fuzzi, 2019). In the past few centuries, human activities have caused the global environment to change dramatically, with global warming serving as the most significant example. Global warming is caused by the increase in greenhouse gases (GHG) and other gaseous and particulate components, mainly as a result of the burning of fossil fuels.

Since the beginning of the industrial age, the impact of human activity on global warming has outstripped that of natural processes (Forster et al., 2007). The 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Pachauri et al., 2014) also reported that anthropogenic forcing contributed to more than half of the global observed average surface temperature change over the period 1951-2010. The increase in GHGs is the dominant cause of rising ocean surface temperatures, increased severity of extreme weather events, declining air quality and instability of natural systems (Luber and Prudent, 2009).

The effects of climate change put the extraordinary improvements in global population health seen in recent decades in jeopardy (Watts et al., 2015). Research on climate change's effects on health has developed, and the evidence of the negative effects has grown. Pachauri et al. (Pachauri et al., 2014) stated that throughout the 21st century, the average health of people was likely to deteriorate due to climate change, especially in developing countries where income was lower. Luber and Prudent (Luber and Prudent, 2009) pointed out that the consequences of global imbalances gave rise to many direct and indirect health problems, including excessive heat-related illnesses, vector and water-borne diseases, increased exposure to environmental toxins, cardiovascular and respiratory diseases exacerbated by reduced air quality, and mental health stress.

The health impacts of climate change are mediated by complex ecological processes. For example, water quality is closely correlated with variations of environmental conditions. When water sources are infected by polluted water or bacterial growth due to meteorological changes, the incidence of diseases increases (Lipp, Huq, and Colwell, 2002). Moreover, some lethal infectious diseases are susceptible to environmental conditions.

The World Health Organisation (WHO) reported an outbreak of Cholera in Africa and southern Asia. Epidemics of Cholera are associated with infected water, which is either caused by seasonal algal blooms or extreme weather events that lead to the mixing of wastewater and drinking water (WHO, 2012). Furthermore, it is reported that over the past two decades, glaciers have been shrinking almost continuously on a global scale, causing sea-levels to rise and threatening freshwater supplies in many parts of the world (Pachauri et al., 2014).

As a developing country and the largest CO_2 emitter in the world, China is under tremendous pressure to decelerate the process of climate change. Along with climate change, the need for rapid urbanisation in China has led to severe air pollution in recent years.

Particulate matter and ground-level ozone (the third most common significant pollutant) pollution is a developing concern that threatens public health, particularly in Chinese megacities (Song et al., 2017). It has been reported that according to the data from the Global Burden of Diseases (GBD) project, 1.6 million deaths in China were the result of air pollution in 2015 (Song et al., 2017; Forouzanfar et al., 2016; Landrigan, 2017).

Air pollution has also created a boom in the market for air filtration equipment, which shows that Chinese citizens consider pollution to be a significant health risk for themselves and their children (Aunan, Hansen, and S. Wang, 2018).

Additionally, water pollution is a big concern in China. According to a survey report of China Youth Daily, 71.8 percent of Chinese people are affected by water pollution (Miao et al., 2015; *Survey shows 71.8% of respondents feel threatened by water pollution* n.d.). Despite recent advances in the supply of safe drinking water, it is believed that more than 200 million Chinese citizens continue to consume contaminated water (H. Liu, 2015; Tao and Xin, 2014).

The World Health Organisation has emphasised the relevance of the interplay between climate change and a variety of other public health problems, stressing the need for interventions aimed at addressing climate change. Addressing global climate issues requires a coordinated response. International cooperation could enhance the effectiveness of the outcomes.

The United Nations Framework Convention on Climate Change (UNFCCC) has been working on a worldwide deal that could decrease emissions to combat environmental change since 1992. In 2015, 196 countries approved the "Paris Agreement" in the 21st UNFCCC Session to manage GHG emission mitigation, adaptation. The financing of these efforts would begin in 2020. The Intergovernmental Panel on Climate Change (IPCC) also provided advice to reduce the risks and effects of climate change (Masson-Delmotte et al., 2018). Aiming to address some of the impacts of climate change, developing countries (e.g. China) have established various pilot projects (Tan et al., 2004).

In the last few years, China has taken significant measures to prevent further environmental deterioration caused by air and water pollution and to protect public health by reducing the impacts of climate change (Song et al., 2017). In the meantime, China committed to an Intended Nationally Determined Contribution (INDC) at COP 21 in Paris in 2015. The established aim was to reach peak emissions by 2030 and reduce carbon intensity by 60-65% from the levels of 2005 (Development and Commission, 2015).

1.1.2 Geo-Engineering

The implementation of contingent valuation (CV) requires two subjects: a hypothetical scenario and a payment instrument. The scenario defines the goods to be valued or the institute responsible for providing the goods or services. Poorly-defined scenarios will lead to meaningless answers (Oezdemiroglu et al., 2002). A good CV survey should describe the hypothetical scenario clearly and accurately. A payment instrument is provided to respondents to "pay for" the goods. Income is frequently used as a payment instrument as individuals are more sensitive to the figures that are attached to income.

In our study, the hypothetical project is “geo-engineering”, which is large-scale intentional invention in the earth’s natural system to curb climate change. The project reduces pollution to give people access to safe water, clean air and green spaces, thus protecting human health from the direct and indirect impact of climate change. The establishment of this project could also significantly improve our environment quality through the comprehensive treatment of air pollution sources, greater control of the quality of living water and the construction of green spaces. However, the risks of carrying out a geo-engineering project include potential damage to the current eco-system and the need for enormous international collaboration efforts.

1.2 Contingent Valuation Method

1.2.1 Introduction

The earliest research on the contingent valuation method can be traced back to 1929 when Pigou (Pigou, 1929) insisted that placing taxes on air and water pollution is correlated with the damage individuals' actions do to the environment. Further, Freeman showed that public goods can be valued in monetary terms (Freeman III, Herriges, and Kling, 2014a). A productivity commission worked on generating environmental benefits because local governments are interested in how much the benefits could be presented to the community (Baker and Ruting, 2014). It is thought that it is difficult to determine the monetary value of environmental benefits since environmental products are not traded in the market. Individuals benefit from environmental sources like fresh air and water and from good environmental quality without even having to pay for the benefit. When the local environment becomes polluted, inhabitants start to realise that they prefer a good living environment and may wish to take action to improve the local environment, through financial or physical interventions. Local governments play a great role in resource allocation and management. It is believed that environmental regulation depends on government intervention which is achieved by implementing environmental protection policies.

The CVM was proposed by Ciriacy-Wantrup (Ciriacy-Wantrup, 1947), who held the opinion that the prevention of soil erosion creates extra benefits for the public. The first application of CVM was carried out by Davis in 1963 (Davis, 1963) when a correlation between survey results and the estimation of value based on travel costs was suggested. In the last few years, the contingent valuation method has been applied extensively to estimate the value of a variety of public programmes in developing countries (Whittington, 1998; Merrett, 2002).

CVM has faced challenges because of biased answers, such as hypothetical bias, starting point bias, strategic bias and information bias (Lewis and Tietenberg, 2019). Hypothetical bias is defined as the possible divergence between the real and hypothetical payments (Freeman III, 1986). Since respondents will not actually pay money for WTP choices, they may give less consideration to instant questions. As a result, it is reported that the hypothetical estimated WTP value was greater than the real WTP values (Neill et al., 1994). Start point bias is also called anchoring bias. This bias arises in the survey instruments in which respondents are given choices from a predefined range of possibilities. The predefined range may affect the final estimated answer.

There are two types of strategic bias, free riding and overpledging (Mitchell and Carson, 2013). Free riding arises when respondents assume others would pay enough, so they can enjoy the free riding. Overpledging occurs when respondents overestimate their WTP value, providing a higher answer to influence the outcome of goods. Information bias occurs when respondents are asked to present the value of a good despite little knowledge. A lack of accurate measurements of a study variable leads to bias as it is believed that more information leads to better decisions.

Despite these challenges, CVM gained popularity after non-use value was recognised as an important subject of total economics value in the study of environmental economics (Venkatachalam, 2004). The NOAA panel also provided cautious support for this method in 1993 (Arrow et al., 1993), it concluded that "subject to a number of best-practice recommendations, CV studies could produce estimates reliable enough to be used in a judicial process of natural resource damage assessment" (D. Pearce, Atkinson, and Mourato, 2006). This conclusion has driven the expansion of CVM, resulting in a large increase in the utilization of this method.

1.2.2 The Classification of Value

The word 'value' has several meanings: it can refer to the price of a product in a supermarket or the amount people are willing to pay for a service. In neo-classical welfare economics, cost-benefit analysis is the most widely used approach for the evaluation of goods or services (Kjaer, 2005). It contains both benefit valuation and cost valuation, providing management and policy makers with sound guidance to achieve a rational allocation of goods (Olsen and R. D. Smith, 2001). When an individual's wealth is determined, the utility level is fixed, if an individual wants to gain more from one of the things in the allocation, he or she should give up another thing in the allocation, in exchange for the same. The amount of something that a person gives up for a benefit is known in welfare economics as their willingness to pay (WTP). It is one of the two measures of welfare in welfare economics. Before discussing methods for estimating the value of environmental goods, we need to

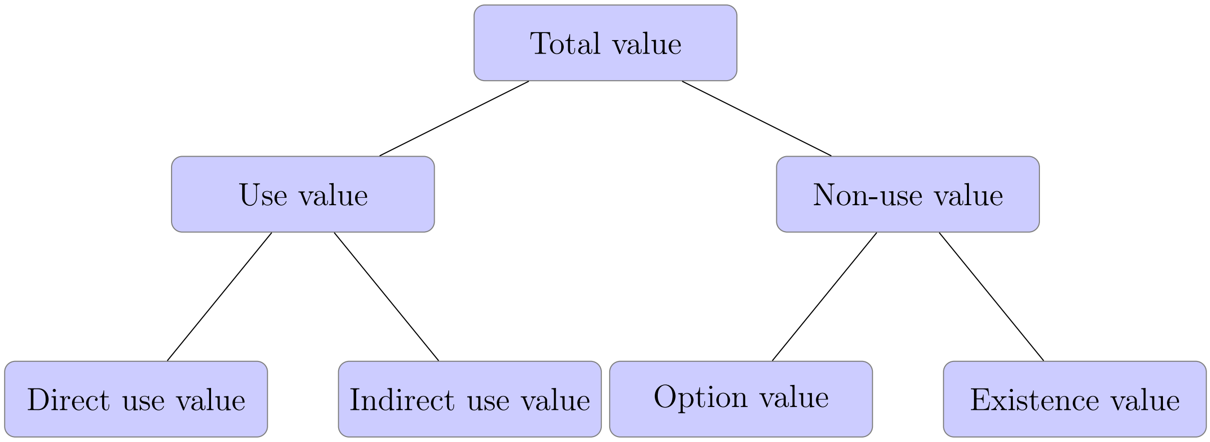


Figure 1.1: Classification of Values

distinguish between the value of environmental benefits.

There are no unified approaches to classifying values due to a lack of consensus on the division criteria. The interpretation and categorisation of the value components vary among researchers, for example, the classification of Freeman et al. (Freeman III, Herriges, and Kling, 2014a) is different from De Groot et al. (De Groot, Wilson, and Boumans, 2002). Whichever type of classification method is used, the main idea is to ensure that no type is ignored or counted more than once. The most widely used classification method was proposed and explained by Baker and Ruting (Baker and Ruting, 2014). Figure 1.1 shows their classification. The total economic value of environmental goods and services can be broadly separated into two components: use and non-use values, and further divided into four types. Use values are explicit benefits of actual use or consumption of the environmental goods (D. W. Pearce and Moran, 1994). Depending on whether individuals get the benefits directly, use value can be further separated into direct use value and indirect use value. Direct use values refer to direct benefits of consumption, for example, picking fruit from trees. The goods with direct use value can usually be traded in the market with a monetary value. Indirect use values refer to the benefits provided by creatures in the ecosystem. For example, we can benefit from the hydrological cycle and photosynthesis of plants.

Non-use values are those that are unrelated to the use or consumption of environmental goods but have an influence on an individual's well-being (Nunes et al., 2002). The benefit of non-use values happens in the future. The option value is one type of non-use value and can be classified into further classes: altruism and bequest values. Altruism values concern others' utility. This is a value placed on maintaining a resource so that others can use it, even if the person willing to pay has no plans or prospective uses for it (e.g.the choice of one person not to smoke benefits others). Bequest value is concerned with future generations. It is the value assigned to a resource for the use of future generations, for example, the protection of the current environment also benefits future generations. Existence value can be seen in biological diversity, it is the value placed on knowing a resource survives (Asafu-Adjaye, 2005).

1.2.3 Valuation Techniques

Economists have developed various techniques for estimating the values of environmental goods. These techniques are based on two classes of methods of non-market environmental goods, the revealed preference (RP) method and the stated preference (SP) method. The main distinction between these two methods is whether or not the scenarios are in the real market.

In the real-market scenario, the value of goods can be estimated directly by comparing it with the price of market goods. Revealed preference theory attempts to understand consumers' preferences for a fixed quality and price bundle within budget constraints. Consumers have the choice of taking or leaving the goods. This choice appears when the value of the goods offered to the individual is greater or less than the price offered. In Freeman's book (Freeman III, Herriges, and Kling, 2014a), it is also called the "observed" method. This method applies to applications where goods have a direct use value. Goods with direct use value already have a price at which they can be traded on the market, making it possible to compare values and prices directly.

For the goods with indirect-use value, option value, and existence value, it is advisable to use the stated preference method. Unlike goods with direct use, these goods do not have an offer price, are not traded on the real market and are called non-market goods. In contrast to real-market research interviews, the stated preference method reveals the economic value through a hypothetical scenario with surveys. The aim of using hypothetical scenarios is to infer people's willingness to pay for a particular benefit by asking them about the value they place on a non-market good or service. For example, China is now facing environmental pollution. Our goal is to investigate the economic value of improving the quality of the environment. Drawing on the idea from CVM, we then set up a hypothetical scenario where there is no environmental pollution after the application of a 'geo-engineering' project. With this assumption, we ask people how much they would be willing to pay, or how much value they would assign to make the project a success.

The revealed preference (RP) method was first introduced by economist Paul Anthony Samuelson in 1938 (Samuelson, 1938). He proposed that an individual's preferences could be inferred by observing a range of choice behaviour towards alternatives. This approach has evolved into choice modelling methods for estimation (McFadden et al., 1973). Later, it was also widely applied to transport demand modelling (Lisco, 1967; Quarmby, 1967). The popularity of this method in the valuation of environmental goods has grown in the 21st century (Sousa et al., 2018; Martini and Tiezzi, 2014). One of the most significant advantages of revealed preference valuation methods is that they use actual observed behaviour rather than hypothetical choices. This approach produces WTP estimates that are often more comprehensive than the results of direct market studies and are therefore useful for environmental policy development. However, RP has its limitations. Revealed preference methods can only be employed to estimate values from real-world data. Thus, they cannot capture non-use value. Moreover, they can only provide reliable WTP estimates for environmental goods if individuals have complete and accurate knowledge of environmental quality and risks. Abley (Abley, 2000) summarised the drawbacks of the revealed preference technique. Due to the limitations of revealed preference methods, environmental economists developed other valuation methods that do not need to observe real world behaviour, which led to the development of stated preference methods (V. K. Smith, 1993).

The stated preference approach is more flexible than the revealed preference approach as it can potentially be applied to any valuation environment. Furthermore, the stated preference approach allows for an investigation of the motivation behind the preference. Stated preference methods can also generate useful data, especially when respondents are provided with varying degrees of knowledge about the goods.

There are two techniques within the stated preference method: the contingent valuation method and choice modelling. The contingent valuation method focuses on non-market goods or services in total, while choice modelling focuses on individual characteristics or attributes.

Conceptual Framework for Non-market Valuation

Contingent valuation aims to measure the compensating or equivalent variation for goods. In welfare economics, there is a conceptual framework for non-market valuation. In the stated preference approach, the derivation of compensating or equivalent variation comes from the study of preferences and utility functions.

In the utility function, a bundle of goods of the same utility level could be exchanged at an exchange rate, and people's preferences will decide which product is preferred over others. Improvements in the environment can change the level of utility and affect the price of goods. Differences in the prices of goods caused by different levels of utility can be accounted for by welfare measures, equivalent measures and compensating measures. The willingness to pay corresponds to the compensating measures. We will describe how the value of willingness to pay is explained by welfare economics.

Starting from preference relation, we assume people make sound judgements when given choices with certain constraints. For example, they can always find a good set of products and services for fixed wealth. In economics, a set of goods and services according to people's preferences is called a consumption bundle. We assume we have two consumption bundles with n units goods or services A and B, $A = (x_1^a, \cdots, x_i^a, \cdots, x_j^a, \cdots, x_n^a)$, $B = (x_1^b, \cdots, x_i^b, \cdots, x_j^b, \cdots, x_n^b)$, where i and j represents the ith and jth good or service in the bundle, x_i and x_j represent the quantity of ith and jth good or service. We also assume that A and B have the same amount of wealth but have different preferences of good ith and jth in the consumption bundle, that is $x_i^a \neq x_i^b$, $x_j^a \neq x_j^b$, then bundle A and B should be in the same indifference curve but in different positions. To better explain it, we assume a case when bundles contain two kinds of goods or services, see Figure 1.2.

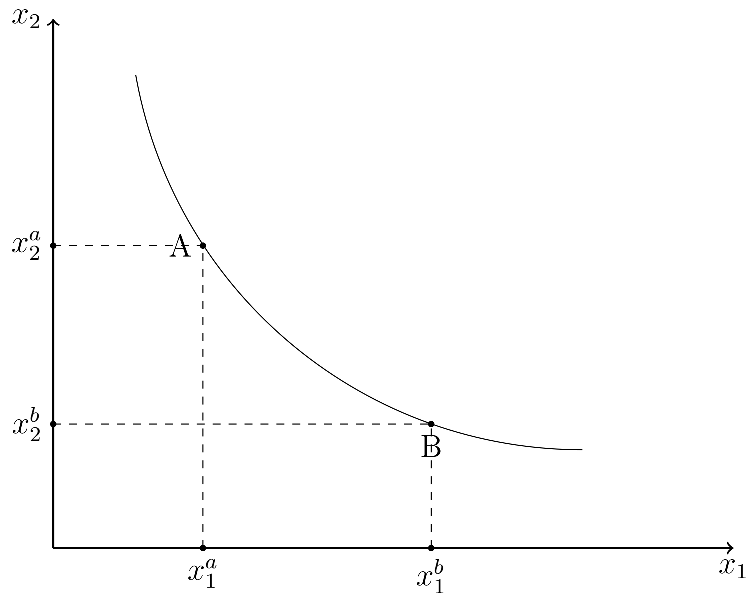


Figure 1.2: Indifference Curve 1

$A = (x_1^a, x_2^a)$, $B = (x_1^b, x_2^b)$, in the same indifference curve, individuals choose bundle A for more x_2 or B for more x_1. To better explain the preference relation in the indifference curve, we introduce some notation, the expression and explanation are in table 1.1.

Notation	Example	Explanation
$\succeq$	$x_1 \succeq x_2$	x_1 is weakly preferred to x_2.
$\succ$	$x_1 \succ x_2$	x_1 is strictly preferred to x_2.
$\sim$	$x_1 \sim x_2$	$x_1 \succeq x_2$ and $x_2 \succeq x_1$.

Table 1.1: Notation of Preference Relation

In Figure 1.3, $x_2^a \succeq x_1^a$, $x_1^b \succeq x_2^b$, $x_1^b \succ x_1^a$ and $x_2^a \succ x_2^b$.

There are two important properties of the indifference curve. The first property is non-satiation, which demonstrates that people always prefer more to less, earning benefits from additional consumption. For example, we consider a bundle $C = (x_1^c, \cdots, x_i^c, \cdots, x_j^c, \cdots, x_n^c)$, if $x_i^c \succ x_i^a$ with $x_j^c \sim x_j^a$ for all $j \neq i$, individuals would prefer bundle C because C has higher utility. Similarly, if $x_j^c \succ x_j^b$ and with $x_j^c \sim x_j^b$ for all $j \neq i$, C is also preferred. It is more obvious in the two-dimensional indifference curve, see Figure 1.3.

We see that C is at the top right of the indifference curve, $C = (x_1^c, x_2^c)$ and $x_1^c \succ x_1^a$, $x_2^c \sim x_2^a$, then individuals would always prefer bundle C compared to A and B.

Another property of indifference curves is substitution. Substitution means a decrease in the quantity of one element in a bundle could be offset by a corresponding increase in the quantity of another element in the same bundle. So changing x_1^c from x_1^b to x_1^a is equivalent to changing x_2^c from x_2^a to x_2^b.

Hicks (Hicks, n.d.) introduced the Marginal Rate of Substitution (MRS) to

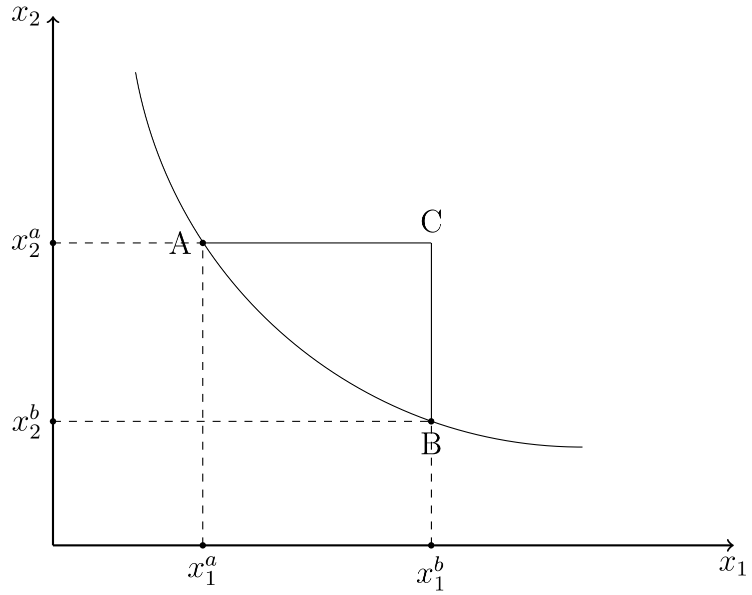


Figure 1.3: Indifference Curve 2

explain substitution. This is interpreted as a trade-off ratio, written as:

$$MRS = \frac{x_j^a - x_j^b}{x_i^b - x_i^a} = \left|\frac{\Delta x_j}{\Delta x_i}\right| = \left|\frac{dx_j}{dx_i}\right|$$

in multiple-dimension. In two dimensions, MRS is the negative slope of AB, see Figure 1.4.

$$MRS = \frac{BC}{AC} = -\frac{dx_2}{dx_1} = -\text{slope of} AB. \tag{1.1}$$

Freeman et al. (Freeman III, Herriges, and Kling, 2014a) conclude that alterations in environmental quality could affect people's welfare in both the market and non-market spheres, through amendments in the prices of market products, changes in the prices of product factors, adjustments in the prices and quantities of non-market products, and changes in the risks people face in their lives. We denote market goods by the vector X, non-market goods by Q, the time by T and

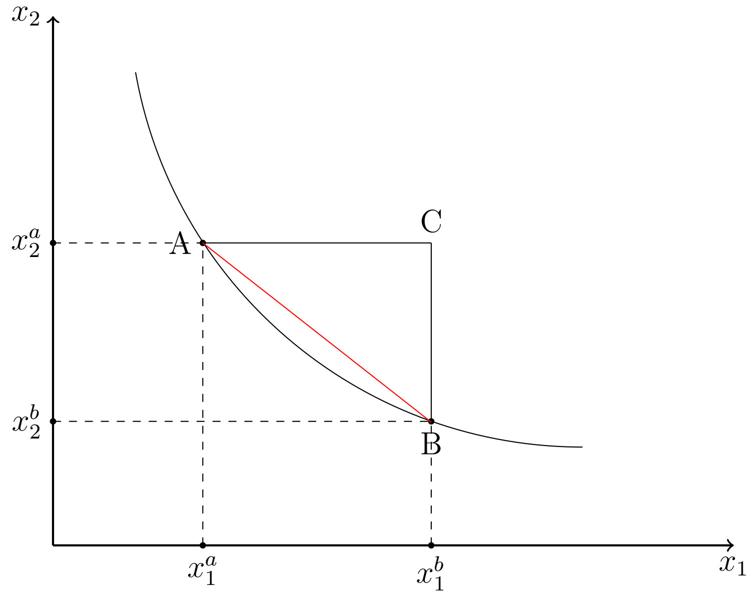


Figure 1.4: Indifference Curve 3

individuals' utility by U. Also, we have the price vector for market goods, denoted P and by an individual's income Y. We list this in table 1.2.

Notation	**Description**
$X = [x_1, x_2, \ldots, x_n]$	A vector of n market goods.
$Q = [q_1, q_2, \ldots, q_k]$	A vector of k non-market goods.
T	A vector of times on activities gaining utility.
$U(X, Q, T)$	The utility function for a bundle of goods (X,Q).
$P = [p_1, p_2, \ldots, p_n]$	Prices of the market goods
Y	Income

Table 1.2: Notations of Factors

We assume that people's preferences remain consistent and that the prices of a market good are fixed. Individuals always want to get the highest utility, so it is a utility maximisation problem, expressed by:

$$\max_{X} U(X, Q) \tag{1.2}$$

$$\text{s.t.} PX \leq Y,$$

where U is a direct utility function expressed by the quantity of goods. Let us assume that there is an optimal solution x_i that maximises this utility function, that is:

$$x_i = x_i(P, Y). \tag{1.3}$$

This solution is constrained by the price and income. If we substitute this optimal solution into the direct utility function, we can obtain a function of price and income, which is the indirect function v, written as

$$v(P, Y) = u(X). \tag{1.4}$$

From another perspective, if we consider utility to be fixed, then for the same level of utility, individuals aim to minimise expenditure. This is known as the expenditure minimisation problem (EPM). The expenditure function is given by

$$e = \sum p_i \cdot x_i \tag{1.5}$$

$$\text{s.t. } u(x) = u^0,$$

where u^0 is the maximum utility with optimal solution x_i. The problem is to find the best combination at the lowest price P and a utility level of u^0. We substitute

P and u^0 into the expenditure function to obtain:

$$e = e(p, u^0). \tag{1.6}$$

We define the solution as

$$h = (P, u^0). \tag{1.7}$$

This function is the compensated demand function, and it is named after John Hicks so it is called the Hicksian demand function (Pollak, 1969).

Assuming that u^0 is a continuous function, the demand for a particular good i for utility u^0 and price P equals the derivative of the expenditure function with respect to the price P,

$$h_i(P, u^0) = \frac{\partial e(P, u^0)}{\partial p_i}. \tag{1.8}$$

Equation (1.8) is Shephard's lemma and re-expressed by Roy's identity (Varian, 1992). Roy's identity relates the demand function to the indirect utility function. Now we substitute the income Y with the expenditure function $e = e(P, u^0)$ in equation (1.3) and get:

$$v = v(P, Y) = v(P, e(P, u^0)) = u(X). \tag{1.9}$$

We have already shown that the improvement of the environment can bring higher utility in the form of fresh air, clean water, wildlife, etc. Assessing the value of the benefits we can derive from improvements is the aim in order to get

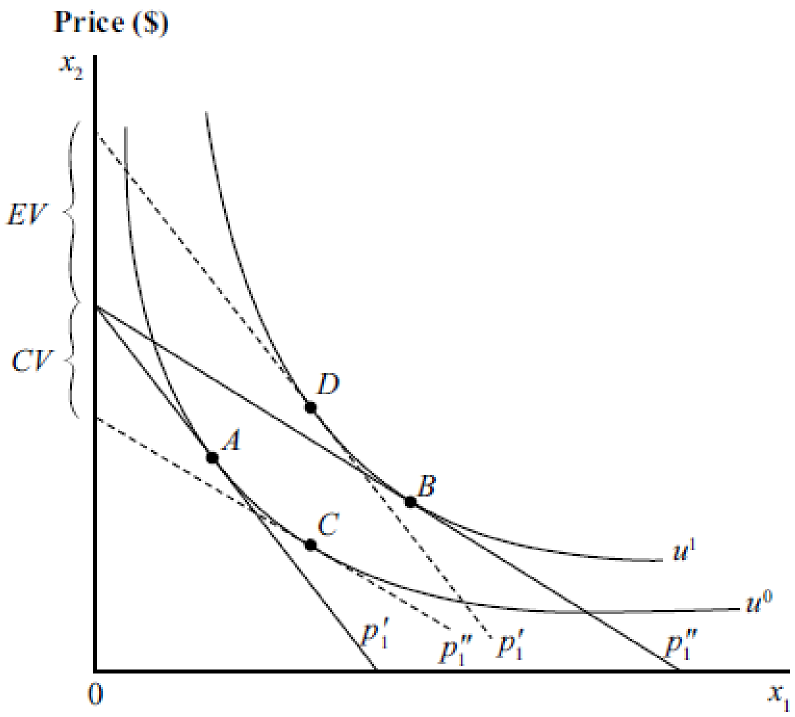


Figure 1.5: Two Measures of the Welfare with Changes in Price
(Freeman III, Herriges, and Kling, 2014b)

the compensating valuation (CV): the indicator of compensating measure. Flores explained that compensatory valuation is the amount of income that people are willing to give up for the implementation of a project that will restore utility to its original level (Flores, 2003). Freeman's interpretation of compensatory valuation is the maximum amount people are willing to pay for the opportunity to spend at a higher price level (Freeman III, Herriges, and Kling, 2014a), as can be seen in Figure 1.5.

In the figure, u^0 is the original utility level, A is a point at which maximum utility can be achieved at price p', the tangent line through A, the exchange rate of goods x_1 and x_2. u_1 represents a higher level of utility after improving the environment. The improvement of the environment could reduce the price of x_1, so the price may shift from p' to p'', keeping x_2 consistent, and the corresponding tangent line intersects with u^1 at point B. This means at price p'', with utility u^1, we have a price of x_2, now we use the same price set and substitute in the original utility level u^0, the price line intersects at point C and we have another price of x_2. The difference between the two prices is represented by CV in the figure. In fact, x_2 can represent the quantity of a product multiplied by its price, and if we give the goods a fixed price, then the number x_2 is equal to the income Y. In this case, CV can be interpreted as the amount of money that people would be willing to pay out of their income Y in order to obtain a higher level of utility. Points A and C are on the same curve, the only difference is the change in the price of the two goods. Let Y^0 represent the current income situation in u^0, with the indirect utility function, CV is one of the solutions to the equation:

$$v(P', Y^0) = v(P'', Y^0 - CV) = u^0, \tag{1.10}$$

CV in expenditure function is the difference of the expenditure at two sets of prices and the integral of compensated demand function from p'' to p':

$$\begin{aligned} CV &= e(p_1', p_2, u^0) - e(p_1'', p_2, u^0) \\ &= \int_{p''}^{p'} h_1(P, u^0) dp_1. \\ &= \int_{p''}^{p'} \frac{\partial e(P, u^0)}{\partial p_1} dp_1. \end{aligned} \tag{1.11}$$

We also see that the expenditure at price p' in utility level u^0 (expenditure at A)

is the same as that at price p'' in utility level u^1 (expenditure at B). Thus,

$$e(p_1'', p2, u^1) = e(p_1', p_2, u^0), \tag{1.12}$$

then, from equation (1.10),

$$CV = e(p_1', p_2, u^0) - e(p_1'', p_2, u^0) \tag{1.13}$$

$$= e(p_1'', p_2, u^1) - e(p_1'', p_2, u^0). \tag{1.14}$$

Now we plot the change of the price on the y axis, we could get compensated demand curve with the decrease in price, which is shown in Figure 1.6.

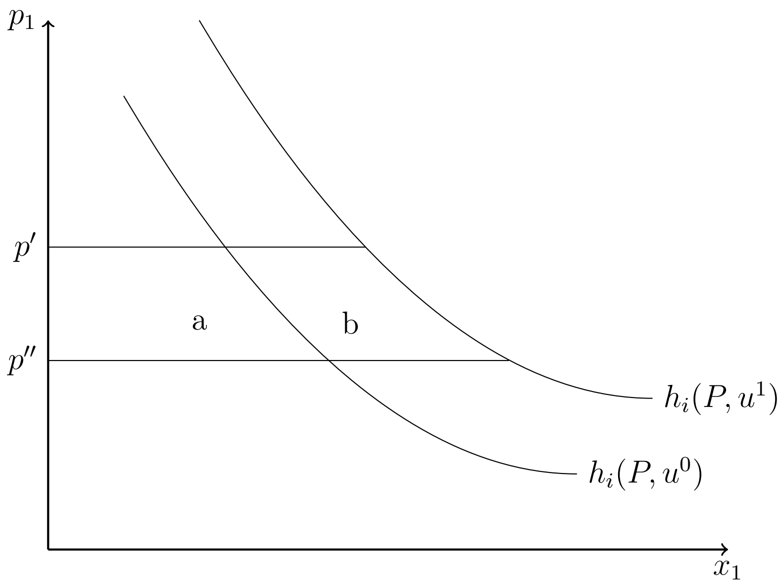


Figure 1.6: Welfare Measures and Compensated Demand Curve

Equations (1.12) shows that value of compensating variation CV is the acreage of the geometric area under curve $h_i(P, u^0)$ between p' and p'', which is marked by a.

$$CV = a \tag{1.15}$$

Having understood how compensating measures can be derived from the utility function in a market situation, we will now use environmental values and derive them in the context of non-market goods. We introduce $Q = (q_1, q_2, \cdots, q_n)$ as the vector of a set of non-market goods. In the case of analysing the variations in non-market goods, we fix the price of market goods and fix all other variables except for the value of non-market goods, replacing one of the market products with a non-market product q_j. For compensating variation and (1.13), we could write compensating variation for non-market goods as:

$$\begin{aligned} CV &= e(P^0, Q^0, U^0) - e(P^0, Q^1, U^0) && (1.16)\\ &= e(P^0, q_j^0, U^0) - e(P^0, q_j^1, U^0) && (1.17)\\ &= \int_{q_j^0}^{q_j^1} p_i(P^0, Q_{j-1}^0, U^0)dq && (1.18) \end{aligned}$$

where q_j increase from q_j^0 to q_j^1. We have to mention that in equation (1.16) and (1.17), the derivative of the expenditure functions with respect to non-market good j is negative of the inverse Hick demand function, so we write the measurement by changing caps and collars to make the variation remain positive. Now we show the change in q_j in a graph to better explain the measurement variations. Figure 1.7 shows that as non-market good q_j increases from q_j^0 to q_j^1, the area the interval forms with the curve $p_i(Q^0, U^0)$ is the compensating variation.

$$CV = a, \tag{1.19}$$

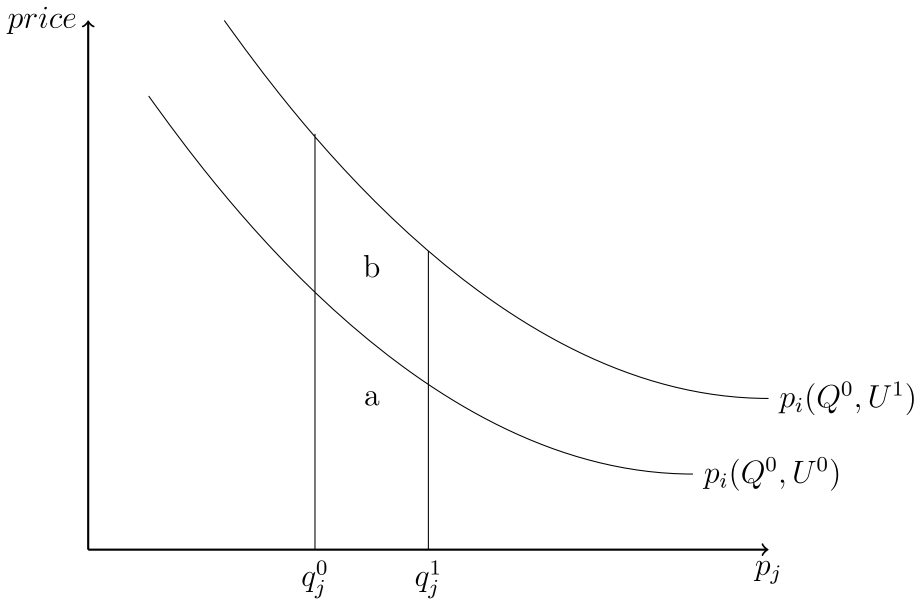


Figure 1.7: Welfare Measures Variation for An Increase in p_j

1.3 Survey Modes

CVM studies need to use surveys to collect feedback and information from a target population for analysis (Gillham, 2008; Kothari, 2004). CVM belongs to stated preference studies which collect data through hypothesis markets for non-market environment goods and services. The choice of survey modes is usually determined by the research topic, purpose and budget. Telephone and face-to-face surveys have been widely used and have proven successful as traditional sampling methods to collect data for CVM studies (Szolnoki and Hoffmann, 2013).

The low cost of telephone surveys has made it the primary mode of data collection for the past sixty years (Szolnoki and Hoffmann, 2013). It is still one of the most popular survey modes even in recent years. However, it has its drawbacks.

The results from Aquilino (Aquilino, 1994) show that response rates for telephone surveys are lower than for face-to-face interviews. Further, Groves (Groves, 1979) pointed to a lower response rate in the telephone mode when it dealing with sensitive issues.

Another low-cost survey model is the online survey. The popularity of online surveys is mainly related to the development of Internet communication. Campbell et al (Campbell, Venn, and N. M. Anderson, 2018) mentioned that the Internet has become very appropriate for data collection and, in the early 21st century, the online mode has become the dominant mode. The most obvious advantage of online surveys is that they are cost-effective. In terms of time, it takes less time for respondents to respond, and in terms of budget, it offers the ability to send out a large number of surveys in a short period of time. As to the performance of Internet surveys in practice when compared to other survey methods, Lindhjem and Navrud (Lindhjem and Navrud, 2011) explored whether Internet surveys have an impact on data quality and welfare estimates, Campbell et al. (Campbell, Venn, and N. M. Anderson, 2018) compared the cost and performance trade-offs of mail and Internet surveys for non-market valuation research, and Taylor et al (Taylor et al., 2009) conducted a study comparing the modal effects of telephone and Internet surveys and concluded that Internet surveys have much lower response rates. In addition, many researchers have argued that web surveys have the disadvantage of lacking representativeness (Duffy et al., 2005; Taylor et al., 2009; Liljeberg and Krambeer, 2012).

Face-to-face interviews use a standardised structured interview protocol and are conducted by trained interviewers in order to minimise bias (Jennings, 2005).

Face-to-face interviews are recommended for high quality and response rate by the NOAA Panel (Arrow et al., 1993). Campbell et al. (Campbell, Venn, and N. M. Anderson, 2018) describe the characteristics of high-quality surveys, some of which are face-to-face interviews. Despite the high cost, the advantages of face-to-face surveys cannot be matched by other survey methods, and the unique survey environment gives them the advantage of controlled interaction whether the interview is conducted in the home or at an intentional intercept site.

Face-to-face surveys can also be used to investigate more complex issues. The first complex issue lies in the manner of data collection, with some studies requiring information measured with instruments. The interviews for this project drew on the experience of the previous China Health and Retirement Longitudinal Study (CHARLS) (*China Health and Retirement Longitudinal Study (CHARLS)* n.d.), in which face-to-face interviews allowed the interviewer to obtain height and blood pressure data from respondents through on-site measurements. The second complication was the formulation of the questions. On one hand, respondents' level of knowledge, comprehension and geographical habits may lead to a different understanding of the question and then influence the result of the survey. On the other hand, respondents may be unfamiliar with the topic in the survey. In a face-to-face interview, the interviewer was able to explain the question or task in more detail to instantly clarify any confusion they have and ensure that respondents did not give up continuously answering due to comprehension difficulty (Schröder, 2016). Moreover, visual demonstration available in face-to-face interviews facilitates respondents' understanding of the survey.

Another strength of face-to-face interviews is that they can conduct longer surveys than other survey modes (Fowler Jr, 2013). The interviews in our project last about 30 minutes, usually longer than the interviews implemented by other survey modes. The response rate remains high because, during interviews, interviewers offer encouragement to respondents to stimulate a sense of contribution to the completion of the survey (Bonnel, Bayart, and B. Smith, 2015). In terms of representativeness, Bonne el al. (Szolnoki and Hoffmann, 2013) showed that face-to-face surveys deliver the most representative results. It is also the best regarding the behavioural characteristics among the three survey modes. Moreover, face-to-face surveys, in principle, have smaller coverage biases since they do not rely on access to a telephone or the Internet (Bonnel, Bayart, and B. Smith, 2015).

The survey method for contingency valuation method has been developed for years, and various eliciting formats have been developed. Early contingent valuation surveys often use an open-ended format. In this format, people are asked for a specific number, like "How much would you like to pay for the protection of Amazon Rain Forest?". The open-ended format is the most direct way to get people's valuation, so it is time-saving. However, it may be difficult for respondents to give their real WTP about a change that they are not familiar with or have never thought about before. As a result, it leads to several flaws relating to response bias, protest answers and respondents ignoring income constraints (Diamond and Hausman, 1994).

The second type is the payment card format. Respondents were provided with cards of different monetary amounts. Respondents choose the card whose value is closer to their willingness to pay. As this type displays the possible bids to respondents, it reduces anchoring bias caused by the start bid. This format has been criticised because respondents' WTPs may be limited to the values listed on the cards.

The third type is the dichotomous-choice question. Unlike the first two types, this type gives respondents two options, "YES" or "NO", to a WTP amount or bid. Respondents say yes or no to a single bid in a single-bounded dichotomous-choice question. For example, the interviewer asks, "Would you like to pay 10 pounds per year to increase vegetation coverage by 1%?". This format is also called the referendum format. In single-bounded dichotomous-choice questions, people are given one bid and asked in one round. In double-bounded dichotomous-choice questions, people will be asked twice in the second round based on the answer in the first round. "Yes" answers in the first round lead to a higher bid in the second round, while "no" answers lead to a lower bid. If an individual answers yes in the first round, he or she will be asked "Would you like to pay 15 pounds per year to make vegetation coverage increase by 1%?", and if his or her answer is no in the first round, he will be asked "Would you like to pay 5 pounds per year to make vegetation coverage increase by 1%?". Iterative bidding is similar to the dichotomous-choice type, but it repeats more times until people change their answer from yes to no or from no to yes. Some researchers think the dichotomous-choice format and iterative bidding format are separate. However, the iterative bidding format may contain more rounds after the double-bounded dichotomous-choice format. In terms of this aspect, iterative bidding is an improved version of dichotomous-choice format.

Applying the dichotomous choice format requires large samples and more information for respondents for efficiency, which results in more spending than other formats. Also, it causes start-point bias. Besides these limitations, the dichotomous choice format is the most widely used approach to elicit information about WTP. It is believed that this format mimics normal market behaviours by accepting or rejecting a listed price that is familiar to respondents. Also, providing bids and letting respondents judge simply the cognitive tasks they face. That is, it is straightforward for respondents to make a decision about their preferences. So in the meantime, it minimises the non-response rate and avoids outliers. Moreover, during the process, interviewers can motivate respondents to answer the question. The follow-up questions to the dichotomous choice question improve the efficiency of elicitation. The NOAA Panel on Contingent Valuation (Arrow et al., 1993) recommended this approach in 1993.

Chapter 2

Survey Design and Data

2.1 Survey Design

Survey questionnaires included several sessions with different topics. The data was collected from the target population's responses to a series of questions. An informative survey should be clear and conducted carefully, otherwise, collecting or interpreting data incorrectly can reduce the validity of results, and even worse, the entire survey can become fruitless. Our survey design referred to the study of Kahan et al. (Kahan et al., 2015).

After the objective was set up for the survey, we designed the questions around the topic based on the objective.

The survey started with warm-up questions. The purpose of warm-up questions is to make respondents comfortable and ready to answer more thoughtprovoking questions in the later sections of the survey (Whitehead et al., 2006). The warm-up section generally is accompanied by materials, such as short paragraphs, charts, or photographs. In this survey, we provided one of the three articles for respondents to read. These articles (Kahan et al., 2015) were about the news on climate change and pollution with either a positive or a negative summary (see Appendix A).

We decided to use the mall intercept face-to-face interview method. The mall intercept is a face-to-face interview technique that requires the interviewer to intercept a random passer-by in a shopping mall and invite them to participate in some research. As we designed the questionnaire to take nearly 30 minutes to complete, we adapted the process to intercept passers-by who decided to find a place to sit while shopping, making them more likely to accept our invitation.

As far as the target population was concerned, we decided to consider location and economic levels as much as we could considering the massive population in China. Andreasen has mentioned that good market research starts with having a good understanding of the target population (Andreasen, 1995). Ideally, the target population should be representative of the whole population in China. Considering the budget and time constraints, we selected four second-tier cities from the south to the north of the country covering in-land and coastal areas. These cities were Harbin in the northeast, Zhengzhou in the central north, Changsha in the central south and Zhuhai a coastal city in the southeast. Our target sample size was 1000, with 250 in each city. The interviews took place in the summer of 2018 in these four cities, the dates are shown below.

- Zhengzhou: 20/07/2018–26/07/2018
- Harbin: 02/08/2018–07/08/2018
- Changsha: 10/08/2018–15/08/2018
- Zhuhai: 18/08/2018–23/08/2018

We used income tax as a payment instrument for WTP. The focus group gave a range of the bid scale, between 0 and 2000. In the study of Kahan et al. (Kahan et al., 2015), there were eight bids across their range 0 to 1500 which were 4, 14, 44, 74,221, 368, 736, 1472. Considering the future comparison with the data from Kehan et al., we made our bids into eight levels across the range, which were 5, 19, 57, 95, 285, 476, 952, and 1904. These scales made the bid trend exponential since the distribution of individual income is exponential. With the consideration that respondents may be more familiar with household bills, we also utilised household bills as another payment instrument. Therefore, we asked two WTP questions: one was based on income tax and the other on household monthly bills. The household bill question would follow immediately after the income tax question, so even if the payment vehicles were at the same level, we made them different but with similar amounts in order to prevent respondents from being influenced by income tax questions. The WTP questions read as follows:

> "At present, there are serious environmental challenges that affect people's quality of life, mainly air pollution, water pollution, and the lack of green spaces. Now suppose that China set up a special project to improve people's living environment, known as "geo-engineering".

> The establishment of this project can significantly improve living environment quality through the comprehensive treatment of air pollution sources, great control of the quality of living water and the construction of green space. Would you be willing to increase your income tax ____ every year in exchange for this project?"

The bids values were randomly chosen from 5, 19, 57, 95, 285, 476, 952 and 1904 in CNY.

> "Would you like to pay for household water and electricity bill, increasing your bill ____ every year to exchange this project? Are you willing?"

The eight random bid values are chosen from 5, 18,54, 90, 271, 453, 906 and 1818 in CNY.

We used an iterative dichotomous choice format for the WTP question design. Compared to other formats, it erases start-point bias. Figure 2.1 shows the process of the iterative dichotomous choice format. The process starts with a random bid. The random number generator creates a random bid list and interviewers choose one of them as an initial bid to start face-to-face interviews. The initial bid is notated Bid_i in the flowchart. The used ones would be removed from the list.

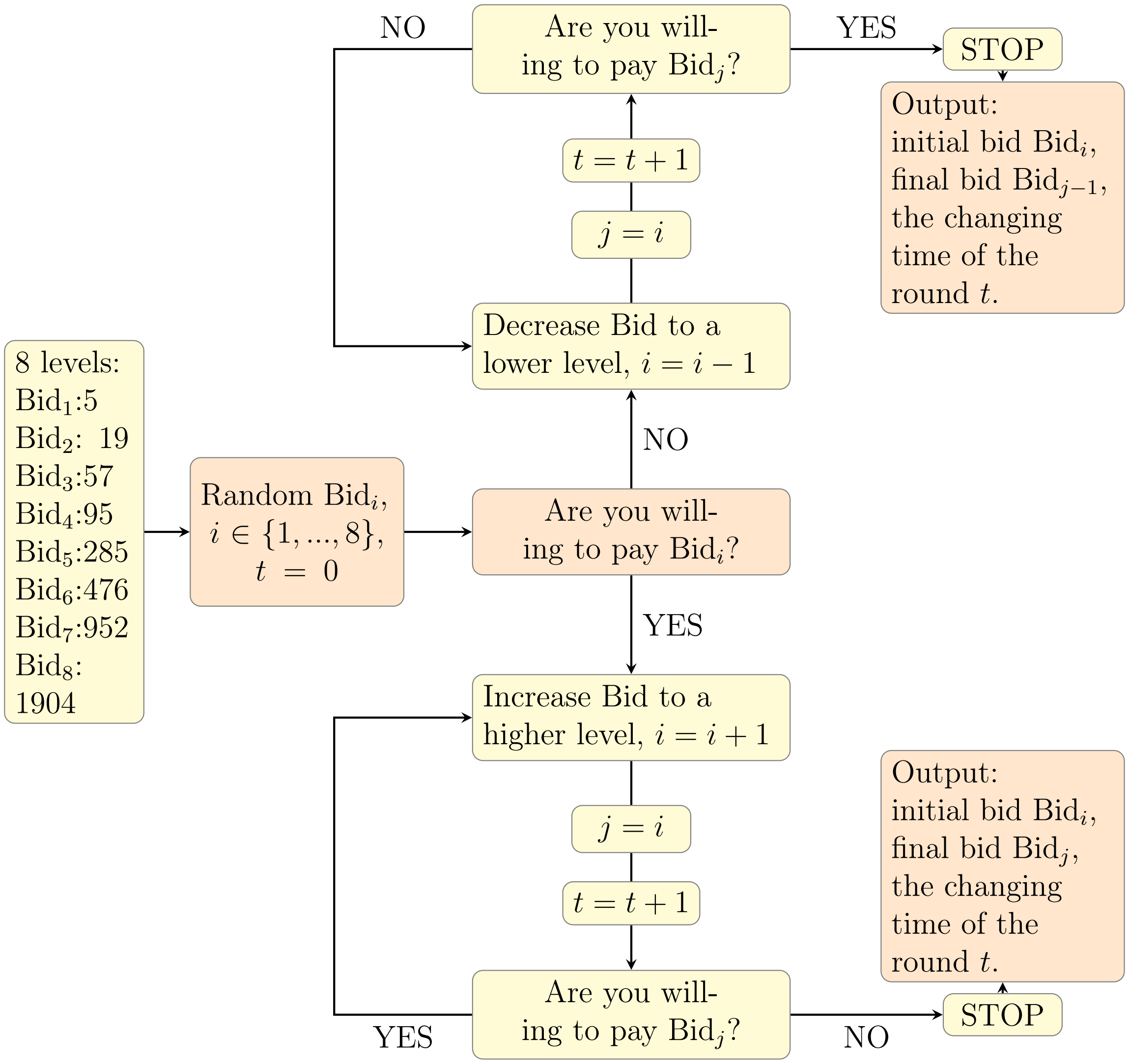


Figure 2.1: Flowchart of the Interview Process

If the answer is “yes” then the interviewer raises the bid to a higher level and repeats the process until the respondent says “no” and the corresponding bid for which he finally says "no" is recorded as the final bid, which is notated Bid_j in the flowchart. Vice versa, if the answer is “no”, a lower bid is given, and repeated until the answer is “yes”. To keep our final bids consistent, in this case, we still record his last bid that said “no”. In this case, the final bid is noted as Bid_{j-1}. In the case of respondents being given the lowest bid with “no” answers or the highest bid with “yes” answers, the process is stopped, and the time of change is $t = 1$.

At the same time, we were curious about how many times it takes to change respondents’ minds from accepting/rejecting a bid to rejecting/accepting a bid. We defined this as the changing time of the round, notated t in the flowchart. Figure 2.2 is an example of the process. There are two possible routes. When

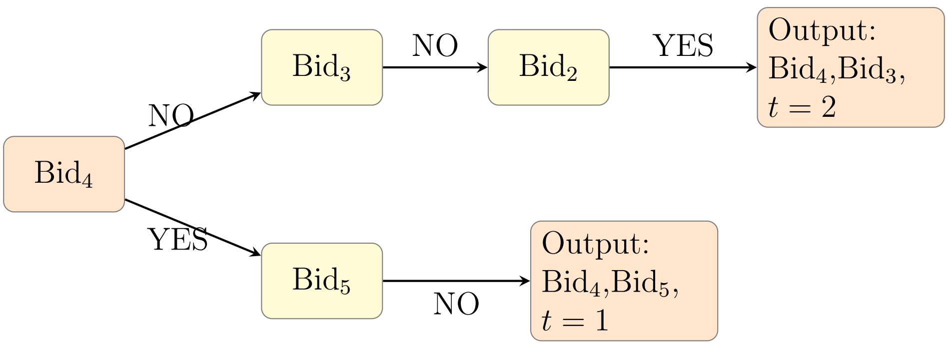


Figure 2.2: An Example of the Interview Process

the respondent is not willing to pay bid level Bid_4, we decrease one level to Bid_3 and ask again. He says NO, then we repeat until he thinks Bid_2 is acceptable and answers YES. As the answer changes from NO to YES, we stop and record the initial bid Bid_4, the final bid Bid_3 and the changing time of the round $t = 2$. If he is willing to pay at an initial bid Bid_4, then we increase one level, but he can not accept Bid_5 and says NO. We stop because the answer differs. We record the initial bid Bid_4 and final bid Bid_5 and the changing time of the round is 1.

Producing a good CV survey requires substantial development work such as focus groups and pre-tests (Stavins, 2007). Focus groups are used to test the draft questionnaire. The focus group is an essential process in which the suitability of the questionnaire is measured. The aim of a focus group or pilot study is to ensure the interviews work the way planned. It gives a rough response rate and reveals potential problems with the questionnaire, such as problems with the length of the design, incomprehensible questions and unclear phrasing. Moreover, it is reported that the CVM is likely to have anchoring and other types of bias (Zografakis et al., 2010).

In this thesis, to make sure that the questions are understandable and the hierarchy of the design is reasonable, we carried out a focus group before putting questionnaires into formal interviews. Focus group discussions with a small group provided insights about issues of interest in the context of assessing non-market impacts. Our focus group was asked questions like this:

> "Do you or your family spend money on avoiding environmental pollution, such as buying dust masks, air cleaning equipment, water filters or related products?" "If so, how much?".

The responses contribute to the capture of people's attitudes toward the environment. Documenting a study is also an essential part of designing and implementing research, helping to record the process, modification, and times of research revision. Table 2.1 records the personal information of some respondents as well as their opinions towards WTP questions. The first contribution of this response is that it helped us understand the WTP range better, the smallest willingness to pay we received was 5, and the largest willingness to pay we were given was 2000. This will eventually influence the bid structure. Another remarkable piece of information was that one of the respondents mentioned that they spent about 2000 Yuan every year buying pollution reduction products, such as clean water filters. This gave us the idea that we should add a question to see how much people usually spend on things to do with pollution. The design of the questionnaire and its content were significantly improved after the use of focus groups. The first version of the questionnaire had 12 pages and 98 questions, making respondents feel stressed. The long pages made them want to give up in the middle; the respondents seemed tired and impatient, counting how many pages were left from time to time. We consolidated the same type of questions into one section rather than displaying them one by one. This vastly decreased the number of pages from 24 to 8.

Before conducting the research in each city, two local interviewers received training. Otherwise, the data may have ended up being even more flawed than usual. This is a crucial step to avoid bias because training makes interviewers produce questions in a consistent way. The training details are given in Appendix C.

No	Gender	Age	Job	WTP	Other information
1	Male	36	Toy factory dept. manager	Not willing, even 5 Yuan	He does not believe the project would be successful
2	Male	48	Steelworker	950	He can accept the max amount below 1000
3	Female	50	Car manufacture	Around 200	Can not pay too much on this because need to consider household expenditure
4	Male	32	University administrator	2000	He hopes he can make some contribution to improve pollution situation
5	Male	25	Card machine salesman	No certain number	He spends around 2000 on masks and water filters per year
6	Female	26	Bank teller	Around 1000	She thinks it is an average number
7	Female	29	Real estate accountant	800	
8	Female	42	Lecture	1500	She mentioned that people may be more sensitive about household bills in China.

Table 2.1: Record from Focus Group

2.2 Data Management and Variables

2.2.1 Data Cleaning

Collecting data using surveys is a practical way of gaining large data sets with consistent and organised information from respondents, and the measured information helps to conduct accurate statistical analysis (Curley et al., 2019). The face-to-face interviews netted 1044 respondents from four cities. The primary data cleaning process included detecting errors from the raw data set and fixing the errors. The details are as follows:

Finding The Errors by Type

Samples with large fractions of missing values: missing data is very common in data-based research, even if it is well designed and controlled (Kang, 2013). We recorded all the questionnaires that we collected regardless of their completeness. Incomplete questionnaires refer to questionnaires that contain part of the information out of the information of 96 variables. Respondents respond to just part of the required questions in a survey for several reasons. Some left the interview process due to urgent calls etc., which left the questionnaires incomplete. Some respondents quit the interview process because they lost interest in continuing on or thought it was much more time-consuming than expected. Another cause of missing data was that respondents skipped particular questions (Brick and Kalton, 1996; Curley et al., 2019). We had a few of these cases during the interview process. These respondents were encouraged to continue the interviews, but they always had the right to quit in the middle. We used the R program to detect the samples with large missing values. We filtered the samples that contained more than 20 missing variables out of 96, 7 samples were removed.

Samples that do not meet the criteria: our target population was determined to be over 16 years old. The main aim of our project was to estimate the WTP from income tax or household bills. Respondents under 16 years old are not allowed to work by the law, so they do not have the concept of income tax if they do not have any income. Although interviewers were trained to find eligible respondents, there was still the possibility of selecting ineligible respondents to take interviews because their actual age may have been challenging to identify from their appearance.

Outliers: an outlier in a data set is a data point that has a significant difference from other observations(Grubbs, 1969). In our survey data set, outliers refer to data points that are outside the range of answers. For example, for the questions examining how strong the agreement is on statements about climate change, the answer range is from 1 to 6, standing for 6 levels. If there is a 9 in this column in the database, then this 9 is an outlier because it is not within the assumed distribution of the answer. In other words, it is too distant from the deemed reasonable sample mean. Misspellings and mistakes on the behalf of the participants mainly cause these types of outliers. The most immediate effect of an outlier is to increase the variance. Besides this, outliers reduce the power of the statistical test, leading to bias and influencing the estimate. More information can be seen in (Yuan and Bentler, 2001) on how outliers affect estimators.

Logical errors: typos and misspellings can cause some logical errors. The most important logic rule is within WTP questions. In the contingent valuation method, we are trying to find the estimates by solving the likelihood function, which contains the logic rules of start bid, finish bid and the corresponding answers of the bids from start bid to finish bid. These can be seen in the next section. Logically, if the answer to the first bid is yes, then the bid is increased to a higher bid. The loop is stopped until the answer of no is given. So the final bid is greater than the first bid when the answer of the first bid is yes. Similarly, the final bid is less than the first bid when the answer to the first bid is no. However, in our database, few samples violate the rules.

Detecting and Fixing the errors

Detecting and fixing missing values: the missing values are easy to detect with R. We used the software to examine the missing values of the database, both vertically by columns or parallel through the use of rows. Vertically, it can count how many missing values there are of each variable. This illustrates how many respondents answered the questions corresponding to the variables in these columns. Parallel across the data, we have the following concerns: The first is the proportion of the complete samples out of the whole population and the valid data sample's proportion; the second is that we can roughly determine the proportion of valid samples by variable groups. This is practically useful when the models only use part of the variables instead of all variables. In practice, we filtered the database, omitting the samples with more than 20 missing values and then got 1037 samples out of 1044. When we constructed the modelling, 11 variables were selected in the model, and we filtered out a few more samples with missing values. Let us look at the summary of the missing data in our research.

Table 2.2 shows the missing values of the original database. 701 samples have no missing values at all. The samples with a large amount of missing values were caused when respondents failed to complete the questionnaires. Then we omitted the samples of more than 20 missing values and got the Table 2.3. 303 samples have 1 missing value because the second question is not designed for all target respondents. Only those assigned to read the third article before the interview should answer the second question, so we need to ignore the effect of this variable to get the correct missing number. Table 2.4 is the summary of missing values after adjusting the variables. 974 respondents finished the whole questionnaire, the completion rate is 93.3%.

No. of NA	0	1	2	3	5	7	8	11	18	24	25	44	57	71	72
No. of Samples	701	303	13	3	9	4	2	1	1	1	1	1	1	1	1

Table 2.2: Number of Missing Value of the Original Dataset

Detecting and fixing the samples that do not meet the criteria: in our samples, 3 samples do not meet the age criteria, 1 sample has the age of 14 and 2 samples have the age of 15. The first way to find these samples is simply using the "sort" function either in R or Excel. The second way is to write a filter function

No. of NA	0	1	2	3	5	6	7	8	11	18
No. of samples	701	303	13	3	9	4	2	1	1	1

Table 2.3: Number of Missing values of the Adjusted Dataset

No. of NA	0	1	2	4	5	6	7	11	17
No. of samples	974	42	4	8	5	2	1	1	1

Table 2.4: Number of the missing value of second adjusted database

with R. These functions are helpful when we change the filter condition. We should not consider samples under the age of 16, so these samples should be ignored during analysis.

Detecting and fixing outliers: the outliers are the observations that are distant from other values in random samples of the population (*What are outliers in the data* n.d.). Given the definition, outliers are not distributed in the normal range in the database. In our project, for scaled questions, with the example of the questions of the first five sections, the outliers within the observations have values which are out of the range of scales 1-6 or 1-7. Researchers have produced multiple methods to detect outliers and these methods can be classified into statistical tests and visual plots. Most statistical tests, such as the z-score method and the Grubbs' test, require the data to be distributed normally (Kwak and Kim, 2017). Some do not require a specific distribution, for example, the Interquartile range (IQR) method, which distinguishes the outliers by calculating the outlier fences. This article (*What are outliers in the data* n.d.) gives a tutorial on how to use the IQR method to find outliers. In practice, performing an outlier hypothesis is not recommended due to its limitations during application. Taking Grubbs' test as an example, it checks for only one outlier. By contrast, the visual methods are both more straightforward and efficient. Both box-plot diagrams and histograms display outliers by use of plots. Box-plot diagrams display outliers by asterisks or other symbols, while histograms emphasise the outliers with isolated bars. In practice, we also construct Tables of answers to detect outliers. Histograms and the "table" function in R both represent the frequency of the answer, which directly divides the outliers into independent groups. Sang (Kwak and Kim, 2017) mentioned three primary methods to treat outliers in a data set. The trimming method removes outliers, the Winsorization method replaces the outliers with expected values, and the robust estimation method produces robust estimators for outliers.

2.2.2 Description of Data

Variables	**Description**	**min**	**max**	**mean**
respondents' attitudes regarding science news/articles about dealing with pollution				
treata	The news/articles the respondents read, 1, "anti-pollution"; 2, "Geoengineering" program; 3, "Control".	1	3	1.979
covina	Agreement on "Nature Science study is convincing", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.231
biaseda	Agreement on "Scientists who did the study were biased", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.321

compua	Agreement on "Computer models are not a reliable basis for predicting impact of CO2", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.293
morsta	Agreement on "More studies must be done before policymakers rely on findings", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.142
gwriska	Agreement on "Global warming brings serious environmental risks", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.158
acredgwa	Agreement on "It is important to take actions to reduce global warming", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.308
gtra	Agreement on "Average global temperatures are increasing.", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.197
hcgtra	Agreement on "Humans activity causing global temperatures to rise", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.708
uabada	Agreement on "Unless action, there will be bad consequences for human beings", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.263

dlnuca	Agreement on "It's very dangerous living near the nuclear station", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.932
Willingness to pay and attitude towards "geo engineering" project				
yorn1a	Dummy variable, the answer of willingness to pay question on income tax: 1, yes; 0, no.	1	1	0.7672
bid1a	The first random bid given to respondents from 5, 19, 57, 95, 285,476, 952 and 1904.	5	1904	253.7
finalno1a	The bid at which respondents said no for the last time.	5	2000	583.7
yorn2a	Dummy variable, the answer of willingness to pay question on household bill: 1, yes; 0, no.	0	1	0.71
bid2a	The random bid given to the respondents from 5, 18, 54, 90, 271, 453, 906 and 1818.	5	1818	271.1
finalno2a	The bid at which respondents said no for the last time.	5	2000	511
geoegba	Agreement on "This geo-engineering project will benefit us", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.688
geoegra	Agreement on "This geo-engineering project will put us in risk", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.045

gidwtpa	Agreement on "Good idea for government to consider about public willing to pay.", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.744
poorlwa	Agreement on "Residents from poor households can afford to pay less, so views will have less weight", 1-6 scale: 1, strongly disagree; 6, strongly agree..	1	6	3.591
grlyscia	Agreement on "Government officials should rely on scientific expertise", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.166
idrighta	Agreement on "Right of individual should not depend on how much others are willing to pay to avoid damage", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.426
paymorea	Agreement on "Already pay too much in taxes to consider paying more", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.357
ntpuba	Agreement on "Don't trust most members of the public to have well informed views", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.673
respondents' health condition				
diseasea	Dummy variable, whether respondents have one of certain diseases: 1, yes; 0, no.	0	1	0.1794

seendoca	Dummy variable, whether respondents have seen a doctor in the past 6 month: 1, yes; 0, no.	0	1	0.2449
inhospa	Dummy variable, whether respondents have seen a hospital in the past 6 month: 1, yes; 0, no.	0	1	0.027
antiagea	Dummy variable, whether respondents take anti-aging drugs or use related products: 1, yes; 0, no.	0	1	0.08679
tantiagea	Continuous answer on how often respondents take anti-aging drug or use related production, ranging from 0 (0 day per months) to 30 (everyday in a month).	0	30	6.348
ifexpena	Dummy variable, whether respondents have expenditure on pollution reduction products: 1, yes; 0, no.	0	1	0.595
expena	Annual expenditure on pollution reduction products.	0	20000	447.4
respondents' attitudes towards society and society life				
faira	Agreement on "Need a fairness revolution" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	5.308

gresa	Agreement on “Government puts too many restrictions on what businesses and individuals.	1	7	4.654
tella	Best way to get ahead in life is to do what told to do” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	3.405
chancea	Most important things in life happen by chance” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.54
pequa	Agreement on “Society works best if power shared equally” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.068
disada	Agreement on “Even disadvantaged should have to make own way in world” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	5.209
nobeya	Agreement on “Society in trouble because people do not obey authority” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	3.454
outca	Agreement on “Course of lives largely determined by forces beyond our control” , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.307

ranpa	Agreement on "Our responsibility to reduce differences in income between rich and Poor" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.959
compea	Agreement on "Better off when compete as individuals" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.293
stricta	Agreement on "Society better off if people in charge imposed strict and swift" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.613
succda	Agreement on "Succeeding in life is a matter of chance" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	3.388
respondents' attitudes towards government functions and social equality				
gintfa	Agreement on "Governments interfere far too much in everyday lives", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.777
lawa	Agreement on "Government needs to make laws that keep people from hurting themselves", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.041

protca	Agreement on "Not governments' business to protect people from themselves", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	2.752
stopa	Agreement on "Government should stop telling people how to live their lives", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.501
limita	Agreement on "Government should put limits on choices individuals can make", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	2.766
goala	Agreement on "Government should do more to advance society's goals, even if limiting Freedom", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.036
equra	Agreement on "Gone too far in pushing equal rights in this country", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	2.934
wtheqa	Agreement on "Society better off if distribution of wealth more equal", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.816
reddifa	Agreement on "Need to reduce inequalities-between rich/poor, Han/ethnic minorities", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.198

seriousa	Agreement on "Discrimination against minorities still a very serious", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.174
sperita	Agreement on "Seems like blacks, women,homosexuals and other groups want special rights", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.68
softa	Agreement on "Society has become too soft and feminine", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.376
Risk score				
guna	Perception of risk from private gun possession, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.851
gwa	Perception of risk from global warming, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.993
airpa	Perception of risk from air-pollution, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.502
watpa	Perception of risk from water pollution, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.629
nucpa	Perception of risk from nuclear power, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.631

legmaa	Perception of risk from legalization of marijuana, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.474
chCFA	Perception of risk from chemical additives in food, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.426
domesa	Perception of risk from domestic terrorism by Muslim extremists, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	9.069
immga	Perception of risk from increased immigration, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	5.685
repta	Perception of risk from lawsuits against reporters and news media for libel, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.277
natecha	Perception of risk from nanotechnology possession, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	3.504
sybioa	Perception of risk from synthetic biology, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	4.357
inexpa	Perception of risk from indoor exposure to second-hand cigarette smoke, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.804
speecha	Perception of risk from speech inciting racial hatred, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.027

genefa	Perception of risk from genetically modified foods, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.247
druga	Perception of risk from illegal drug trafficking, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	9.011
grega	Perception of risk from government regulation of businesses, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.616
teenpa	Perception of risk from teenage pregnancy, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	5.84
epelea	Perception of risk from exposure to electromagnetic fields from powerlines, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	5.896
gedua	Perception of risk from cuts in government support for higher education, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.619
chvaa	Perception of risk from childhood vaccinations, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	5.835
pwara	Perception of risk from military participation in war zones, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.493

budgeta	Perception of risk from government budget deficits, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.757
fuela	Perception of risk from the accumulation of spent nuclear fuel from nuclear power plants, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.344
clicha	Perception of risk from Climate change, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.619
Sociodemographic characteristics				
agea	respondents' age.	16	75	32.7
genda	respondents' gender, 1, female.	0	1	0.5189
edua	The years respondents get education in school.	0	10	7.619
eduwa	Dummy variable, the way to accept education: 0, part time; 1, full time.	0	1	0.8949
emplya	Dummy variable, employment status: 0, part time; 1, full time.	0	1	0.7493
mincomea	Monthly income.	1500	20000	6548
ethnica	Dummy variable, ethnic: 1 Han; 0, others.	0	1	0.9412
maritala	Dummy variable, marital status: 1 married; 0, others.	0	1	0.5763
politicala	Dummy variable, political parties.: 1, in political parties; 0, the masses.	0	1	0.2558

imreliga	Agreement on "importance of religion", ranging from 1-4: 1, not at all important; 4, very important.	1	4	2.497
ideologya	respondents' ideology, 1-5 scale: 1, very conservative; 5,very liberal.	1	5	3.897
intnewa	respondents' interest in news and public affairs, 1-4 scale: 1,hardly interested; 4, most interested	1	4	1.925

Table 2.5: Descriptive Statistics

In total, 1044 questionnaires were collected. The summary statistics are represented in Table 2.5. The data codebook is seen in Appendix D.

In the first part of the questionnaire, we asked respondents to read one of three news items or articles. Each news/article introduced a different approach to coping with environmental pollution. Following the reading, ten statements were given to respondents; each had 6 scales to choose from, with 1 indicating strongly disagree and 6, indicating strongly agree. The statements were to do with the content in the articles/news or regarding reflections triggered by the articles/news. In the second part, willingness to pay questions on income tax and household bills were implemented separately. The answer to the random first bid, the second bid and the bid at which respondents said no for the last time were recorded. Then eight statements were given with six scales, 1 indicates strongly disagree, and 6 indicated strongly agree. These statements were all connected to a "geo-engineering" project within the WTP questions. The research was also designed to cover the information on respondents' health conditions to examine the effect of health conditions on WTP. Some of them had dummy answers. For example, respondents were asked whether they had an illness or had been admitted to the hospital in the last six months. Some of them were continuous variables. For example, respondents were asked how often they took anti-ageing products daily and the annual expenditure on pollution reduction products. Part four had the same question form as in the second part, and it contained twelve statements with seven scales. The statements listed in this part attempted to reveal respondents' attitudes towards society, occupational and/or social lives. The same question form was also present in the fifth part, in the form of 12 statements with 6 varying scales. The design of this part was to see respondents' attitudes towards government functions and social equality. In the sixth part, twenty five specific objects or phenomena were listed. Respondents could rate their risk to humans by scoring them from 0, no risk at all, to 10, an extreme risk. These specific objects were grouped into three categories. One category listed the items about environmental issues, pollution or human activity in the environment, such as the risk from water pollution. The second category listed social phenomena like increased immigration. The final set of objects belonged to the category of modern technology. Section seven collected information on respondents' socio-demographic characteristics, age, income, social status and etc.

According to the result of the first round, the bid which was the closest to the median of WTP was 476, which was accepted by 48.72% of the participants.

According to the final results, the bid which was the closest to the median of WTP was 285, which was accepted by 49.74% of participants, demonstrating the bid scales were reasonable.

2.3 Variable Selection for the Modelling

The logistic regression model will fit our data well because of the dependent variable being binary (yes or no). In theory, not all of the variables were included in the regression model because we wanted to ensure that our model was as realistic as possible, and the degree of its precision would have kept decreasing with the addition of irrelevant variables. Therefore we needed to make decisions from a range of variables. We have two principles when we make decisions. First and most important, as mentioned above, only the variables related could be used to make them fit within the confines of the model. Second, based on the first step, it was important to screen the ones which could have actual practical significance to the independent variable. In this step, we also screened out the variables which had collinearity.

We utilised the stepwise method to select variables and now we will discuss the exact procedure. This step was always achieved by statistics software, with the utilisation of R, using both forward stepwise and backward stepwise. Forward stepwise is a method which starts from zero variables and adds more, one by one, step by step, through analysis into which variable could increase R^2 most. The procedure ends once all the significant variables are added, individually. Backward stepwise is the opposite procedure, beginning with all of the variables and decreasing the number of variables by detecting the most insignificant variables, step by step. What we used was a stepwise selection which combines the above two methods. It has two significant levels, one is for adding variables, and another one is for removing variables. Each iteration will add one variable and remove one variable from a set of candidate explanatory variables based on the significance, the most significant one entering and the most insignificant one being removed. This combination method can be faster and more efficient than a single procedure. The stepwise outcome of variable selection is in Appendix E.

Chapter 3

Testing of the Multiple Rounds Effect Using the Traditional Maximum Likelihood Estimation Method

3.1 Specification of the WTP Model and Bid function

Chapter one illustrated that people's maximum willingness to pay is measured through compensating variation (CV), that is $WTP = CV$. Equation (1.10) can be rewritten as:

$$v(p, q^0, Y) = v(p, q^1, Y - WTP), \tag{3.1}$$

Different frameworks have been developed for WTP models, with two frameworks being the most commonly applied. The first approach is the utility difference framework presented by Hanemann (Hanemann, 1984b). This method is also favoured by Seller, Stoll, and Chavas (Seller, Stoll, and Chavas, 1985), and McFadden and Leonard (McFadden and Leonard, 1993). An alternative framework was proposed by Cameron (Cameron, 1988) and is known as the bid function model. These two frameworks estimate the bid function in a similar manner but with different interpretations. The former derives the bid function explicitly from the principles of welfare economics while the latter models the bid function directly. The utility difference model expresses WTP in terms of the equivalent utility change for the change in the provision of the non-market good. Meanwhile, in the bid function model, the estimation is the WTP for the change in the provision of the non-market good. In the literature on CV methods, there is no agreement on which method of constructing a bid function is preferred (Bateman and Department of Transport Großbritannien, 2002). In this thesis, the single-bounded modelling approach closely follows the statistical analysis of discrete-response CV data of Hanemann (Hanemann and Kanninen, 1996) and the double and triple modelling approach follows the contingent valuation method introduced by Cameron and Quiggin (Cameron and Quiggin, 1994).

In order to derive WTP, the first step is to establish a dichotomous-choice (DC) model and then build a probability model of WTP. The answer to the WTP questions is dichotomous, either yes or no. In the model, we take the answer as an independent variable,

$$y = \begin{cases} 1 & \text{yes,} \\ 0 & \text{no.} \end{cases} \tag{3.2}$$

In general cases, the probability of the ith respondent responding yes is a function H of the given bid and the other random covariates.

$$\Pr(y_i = 1) = H_i(B_i, Z_i), \tag{3.3}$$

where B_i represents the given bid for the ith respondent and Z_i is the vector of other covariates. Therefore, the probability of a "NO" response is:

$$\Pr\{y_i = 0\} = 1 - H_i(B_i, Z_i). \tag{3.4}$$

To connect the statistical model with the utility function, we introduce the random utility maximisation (RUM) model, which was introduced by Hanemann (Hanemann, 1984a). The RUM model assumes that respondents make their choice based on their identified preferences while for researchers, the respondents' choice also contains uncertain factors or stochastic components, denoted ϵ. Thus, for researchers, the utility function includes the stochastic term ϵ. The indirect utility function is then rewritten as $v = (q, Y, \epsilon)$. If $q^1 \geq q^0$, q^1 is an improvement of q^0, then the change reflected in the utility function is $v(q^1, Y, \epsilon) \geq v(q^0, Y, \epsilon)$. Thus we have

$$v(q^1, Y - WTP, \epsilon) = v(q^0, Y, \epsilon). \tag{3.5}$$

During the interview, respondents are offered a bid of B and asked if they are willing to pay this amount. They will answer "yes" if they believe that the sum of utilities in q^1 at a cost of B is at least the same as the utility in q^0, i.e. if $v(q^1, Y - B, \epsilon) \geq v(q^0, Y, \epsilon)$, where B is their willingness to pay. Thus, the probability of answering "yes" is represented by the formula

$$\Pr\{y = 1\} = \Pr\{v(q^1, Y - B, \epsilon) \geq v(q^0, Y, \epsilon)\}. \tag{3.6}$$

If we substitute (3.5) into the right-hand side, we get

$$\Pr\{y = 1\} = \Pr\{Y - B \geq Y - WTP\}, \tag{3.7}$$

$$= \Pr\{WTP \geq B\}. \tag{3.8}$$

We assume that the WTP of ith respondent has the form

$$WTP_i = x_i^T \beta + \epsilon_i \tag{3.9}$$

where i represents ith respondent, ϵ is the stochastic term.

3.1.1 Single-bounded DC Model

The statistical model in (3.4) is consistent with the economic model to be maximised if, and only if, the right-hand side of (3.4) can be interpreted as the cumulative distribution function (c.d.f) of the stochastic WTP. The choice of a specific WTP model depends on the distribution of WTP. We use the final bid to see the distribution of WTP, the number of respondents' final bids at 5, 19, 57, 95, 285,

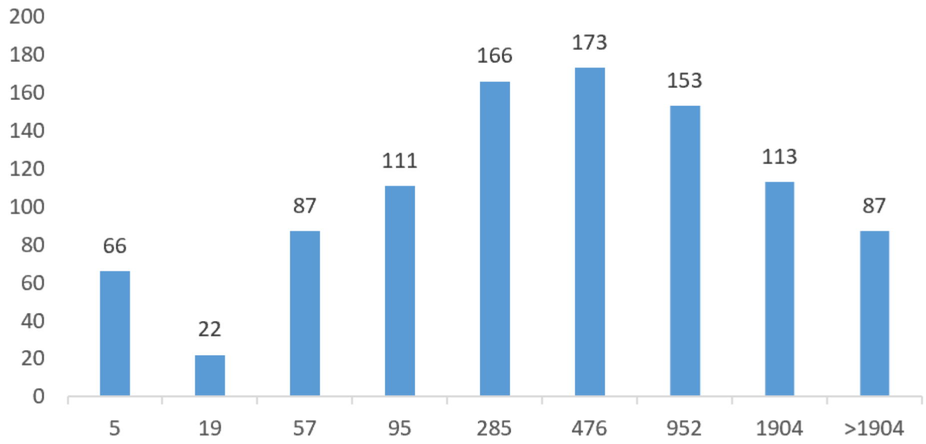


Figure 3.1: Distribution of final bid

476, 952, 1904 and the bid greater than 1904 are 66, 22, 87, 111, 166, 173, 153, 113, and 87, which are normally distributed, see figure 3.1.

We start with the single-bounded DC case with WTP following the normal distribution with $E\{WTP\} = u$, $\text{var}\{WTP\} = \sigma^2$, and assume G is the c.d.f of the standard variate $z = \frac{WTP-u}{\sigma}$, equation (3.3) becomes

$$\begin{aligned}
\Pr\{y_i = 1\} &= 1 - G_{WTP}(B_i) && (3.10)\\
&= 1 - G\left(\frac{B_i - u}{\sigma}\right) && (3.11)\\
&= \Phi\left(\frac{u - B_i}{\sigma}\right) && (3.12)\\
&= \Phi\left(\frac{x_i^T\beta - B_i}{\sigma}\right). && (3.13)
\end{aligned}$$

and is a probit model.

The aim of the maximum likelihood function method is that, given some observations, it tries to find the most likely parameters. In practice, this is done by seeking the corresponding parameters to satisfy the likelihood function. Finally, we denote the unknown parameters by a vector θ. What we already know from previous observations is the vector of independent variables X and the vector of responses Y. For $i = (1, 2, \cdots, n)$ observations, the likelihood function is given by

$$L(\theta \mid Y, X) = \prod_{i=1}^{n} P(Y \mid X, \theta). \tag{3.14}$$

For convenience, we take the logarithm of both sides and get

$$l(\theta \mid Y, X) = \sum_{i=1}^{n} \log P(Y \mid X, \theta). \tag{3.15}$$

In the single-bounded DC case, the log-likelihood function can be written as

$$l = \sum_{i=1}^{n} \left\{ y_i \log P_i + (1 - y_i) \log (1 - P_i) \right\}. \tag{3.16}$$

P_i in this case is the responsibility of the ith observation. Maximising the log-likelihood function requires that it satisfies the first-order condition

$$\frac{\partial l(\theta)}{\partial \theta} = \sum_{i=1}^{n} \frac{\partial \log P(y_i \mid x_i, \theta)}{\partial \theta} = 0. \tag{3.17}$$

When WTP follows a normal distribution, the likelihood function is

$$L = \prod_{i=1}^{n} \Phi\left(\frac{x_i^T \beta - B_i}{\sigma}\right)^{y_i} \left(1 - \Phi\left(\frac{x_i^T \beta - B_i}{\sigma}\right)^{(1-y_i)}\right). \tag{3.18}$$

The log-likelihood function is

$$
\begin{aligned}
l = \sum_{i=1}^{n} \Bigg\{ & y_i \cdot \log \Phi \left(\frac{x_i^T \beta - B_i}{\sigma} \right) \\
& + (1 - y_i) \cdot \log \left(1 - \Phi \left(\frac{x_i^T \beta - B_i}{\sigma} \right) \right) \Bigg\}.
\end{aligned} \tag{3.19}
$$

3.1.2 Double-bounded DC Model

A double-bounded dichotomous model is built by asking people twice in contingent valuation methods, requiring a degree of complex analysis since the second question depends on the response to the first question. It is not just a simple addition or subtraction of the bid, it is the combination of the response to the first and second questions. Let B_1 represent the first bid given to respondents and B_2 represent the second bid. The answers in double-bounded dichotomous models have four cases.

1. YES-YES (YY) answer: In this case, respondents respond YES to B_1 which makes us increase bid to B_2, to which they still respond YES. In this case, $B_2 > B_1$ we get $WTP \geq B_2$.

2. YES-NO (YN) answer: In this case, $B_2 > B_1$ and we get $B_1 \leq WTP < B_2$.

3. NO-YES (NY) answer: In this case, the respondents respond NO to B_1, then we decrease the bid to B_2 which they are willing to accept. In this case, $B_2 < B_1$, and we get $B_2 \leq WTP < B_1$.

4. NO-NO (NN) answer: In this case, $B_2 < B_1$ and we get $WTP < B_2$.

In double-bounded model, we let $j = (1, 2)$ represents the jth round, then the WTP for ith respondent is

$$WTP_{ii} = x_{ij}^T \beta + \epsilon_{ij} \tag{3.20}$$

$WTP_{i1} = WTP_{i2}$ because people's preference remain unchanged in the first and second round, so WTP of ith respondent is WTP_i. When assuming that WTP follows a normal distribution with $E\{WTP\} = u$, $\text{var}\{WTP\} = \sigma^2$, the probability of ith respondents' answer in each case can be written as

$$\begin{aligned} \Pr(YY) &= \Pr\left(WTP_i > B_1, WTP_i > B_2\right) \\ &= \Pr\left(u > B_1, u > B_2\right) \\ &= 1 - \Phi\left(\frac{x_i^T \beta - B_2}{\sigma}\right), \end{aligned} \tag{3.21}$$

$$\begin{aligned} \Pr(YN) &= \Pr\left(WTP_i \geq B_1, WTP_i < B_2\right) \\ &= \Pr\left(u \geq B_1, u < B_2\right) \\ &= \Phi\left(\frac{B_2 - x_i^T \beta}{\sigma} - \frac{B_1 - x_i^T \beta}{\sigma}\right), \end{aligned} \tag{3.22}$$

$$\begin{aligned} \Pr(NN) &= \Pr(WTP_i < B_1, WTP_i < B_2) \\ &= \Pr(u < B_1, u < B_2) \\ &= \Phi\left(\frac{B_2 - x_i^T \beta}{\sigma}\right), \end{aligned} \tag{3.23}$$

$$\begin{aligned}
\Pr(NY) &= \Pr(WTP_i < B_1, WTP_i \geq B_2) \\
&= \Pr(u < B_1, u > B_2) \qquad (3.24) \\
&= \Phi\left(\frac{B_1 - x_i^T\beta}{\sigma} - \frac{B_2 - x_i^T\beta}{\sigma}\right).
\end{aligned}$$

The likelihood function is

$$L_j(u|B) = \Pr(YY)^{YY} \times \Pr(YN)^{YN} \Pr(NY)^{NY} \times \Pr(NN)^{NN}, \qquad (3.25)$$

The log-likelihood function may thus be written as

$$l_j(u \mid B) = \sum_{j=1}^{n} \big(I_{YY} \Pr(YY) + I_{YN} \Pr(YN) + I_{NY} \Pr(NY) + I_{NN} \Pr(NN)\big), \qquad (3.26)$$

I_{xy} is an indicator function, where $I_{xy}(X, Y) = 1$ if $X = x$ and $Y = y$, and zero otherwise. In this case, we ease notation by suppressing the inputs and stating that if the respondent response is YY, then $I_{YY} = 1$ and all other indicators are zero.

3.1.3 Triple-bounded DC Model

The double-bounded dichotomous model is built by adding one more follow-up question after the second follow-up question. We have noted that in double-bounded CVM, we have four cases. We now add two more cases after each of these four cases. The flowchart in Figure 3.2 represents the situation.

In Figure 3.2, I before bid represents initial and similarly an H represents

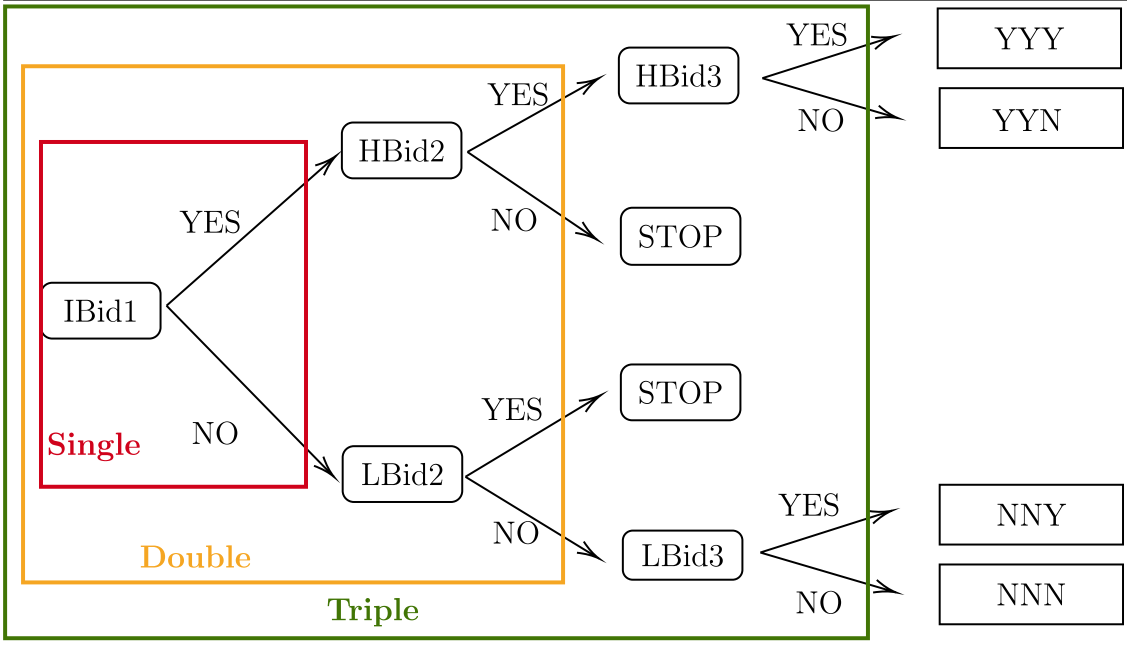


Figure 3.2: Triple-bounded Procedure and Output

higher and L represents lower.

The three-bounded process output 8 answer combinations: YYY, YNY, YYN, YNN, NYY, NNY, NYN. NNN, where Y means YES and N means NO. With the method we are using we only output 4 cases because the procedure stops when the answers change according to the given bid. So, unlike in the literature, we do not have outputs which change answers more than once. This gives us only 4 possibilities. This is described in Figure 3.2. Let B_3 represent the bid which is given to the respondent in the third round.

1. YES- YES- YES (YYY) answer: respondents respond YES to B_1 which makes us increase the bid to B_2, they still respond YES, so a higher bid B_3 is given. In this case, $B_3 > B_2 > Bid_1$ and we see that $WTP \geq B_3$.

2. YES- YES- NO (YYN) answer: In this case, $B_3 > B_2 > B_1$, respondents say YES to B_1, say YES to B_2 but say NO to B_3. Thus we see that $B_2 \leq WTP < B_3$.

3. NO- NO- YES (NNY) answer: In this case, $B_1 > B_2 > B_3$, respondents say NO to B_1 and to B_2 but say YES to B_3.

4. NO- NO- NO (NNN) answer: In this case, $B_1 > B_2 > B_3$ and we see that $WTP < B_3$.

In triple-bounded model, $j = (1, 2, 3)$. Since ith respondent's preference is maintained $WTP_{i1} = WTP_{i2} = WTP_{i3}$. When WTP follows a normal distribution, $E\{WTP\} = u$, $\text{var}\{WTP\} = \sigma^2$, the probability of ith respondents' answer in each case can be written as

$$\begin{aligned}\Pr(YYY) &= \Pr(WTP_i > B_1, WTP_i \geq B_2, WTP_i \geq B_3)\\ &= \Pr(u > B_1, u \geq B_2, u \geq B_3)\\ &= 1 - \Phi\left(\frac{B_3 - x_i^T\beta}{\sigma}\right),\end{aligned} \tag{3.27}$$

$$\begin{aligned}\Pr(YYN) &= \Pr(WTP_i > B_1, WTP_i > B_2, WTP_i < B_3)\\ &= \Pr(u > B_1, u > B_2, u < B_3)\\ &= \Phi\left(\frac{B_3 - x_i^T\beta}{\sigma} - \frac{B_2 - x_i^T\beta}{\sigma}\right),\end{aligned} \tag{3.28}$$

$$\begin{aligned}\Pr(NNY) &= \Pr(WTP_i < B_1, WTP_i < B_2, WTP_i > B_3)\\ &= \Pr(u < B_1, u < B_2, u > B_3)\\ &= \Phi\left(\frac{B_2 - x_i^T\beta}{\sigma} - \frac{B_3 - x_i^T\beta}{\sigma}\right),\end{aligned} \tag{3.29}$$

$$\begin{aligned}
\Pr(NNN) &= \Pr(WTP_i < B_1, WTP_i < B_2, WTP_i < B_3) \\
&= \Pr(u < B_1, u < B_2, u < B_3) \\
&= \Phi\left(\frac{B_3 - x_i^T\beta}{\sigma}\right).
\end{aligned} \tag{3.30}$$

The likelihood function is

$$\begin{aligned}
L_j(u \mid B) = {} & \Pr(WTP_j > B_1, WTP_j \geq B_2, WTP_j \geq B_3)^{YYY} \\
& \times \Pr(WTP_j > B_1, WTP_j > B_2, WTP_j < B_3)^{YYN} \\
& \times \Pr(WTP_j < B_1, WTP_j < B_2, WTP_j > B_3)^{NNY} \\
& \times \Pr(WTP_j < B_1, WTP_j < B_2, WTP_j < B_3)^{NNN},
\end{aligned} \tag{3.31}$$

and so the log-likelihood function is

$$l_j(u \mid B) = \sum_{j=1}^{n} \big(I_{YYY}\Pr(YYY) + I_{YYN}\Pr(YYN) + I_{NNY}\Pr(NNY) + I_{NNN}\Pr(NNN)\big), \tag{3.32}$$

where I_{xyz} is an indicator function as in (3.26).

3.2 Explanatory Variables and Hypotheses Testing

3.2.1 Explanatory Variables

In the models, the independent variable is the binary response towards the first random bid given to respondents. Figure 3.3 shows the response rate to the first random bid assigned to respondents. Bid1 represents the amount of money respondents are willing to give up from income tax while bid2 represents the amount that respondents are willing to give up from household bills. CNY is the unit of Renminbi (RMB). In the figure, in the horizontal direction, the width of the histogram corresponding to each bid level represents the proportion of respondents in this level out of the total number of eight levels. Vertically, each histogram is divided into two blocks, the top one representing the proportion saying "no" and the bottom one representing the proportion saying "yes". So, the size of these small squares is their size in the overall sample. This diagram very clearly indicates that no matter the bid, as the bid increases, the number of people saying "yes" decreases and the number of people saying "no" increases. This figure also provides a preliminary answer to the question of whether Chinese people are more sensitive to increases in household bills or in income tax. To better explain this situation, we have defined the proportion of yes responses as the “yes ratio”. As can be seen from the graph, the yes-ratio is higher for bid1 than for bid2 at level 1, while the yes-ratio is lower for bid1 than for bid2 at level 8. As bids increase to a higher bid level, the yes-ratio for bid1 falls faster than the yes-ratio for bid2. This also means that, within each tier, there is a greater difference in the consent rate for bid1 than for bid2. As a result, people may be more sensitive to income tax than to household bill payments.

For dependent variables, the WTP model contains a set of attitudinal and socioeconomic variables. Detailed definitions and the associated sample statistics are provided in Table 3.1. The attitudinal variables are the significant variables selected by the stepwise method. The standard socioeconomic variables are respondents’ age, gender, income and ideology.

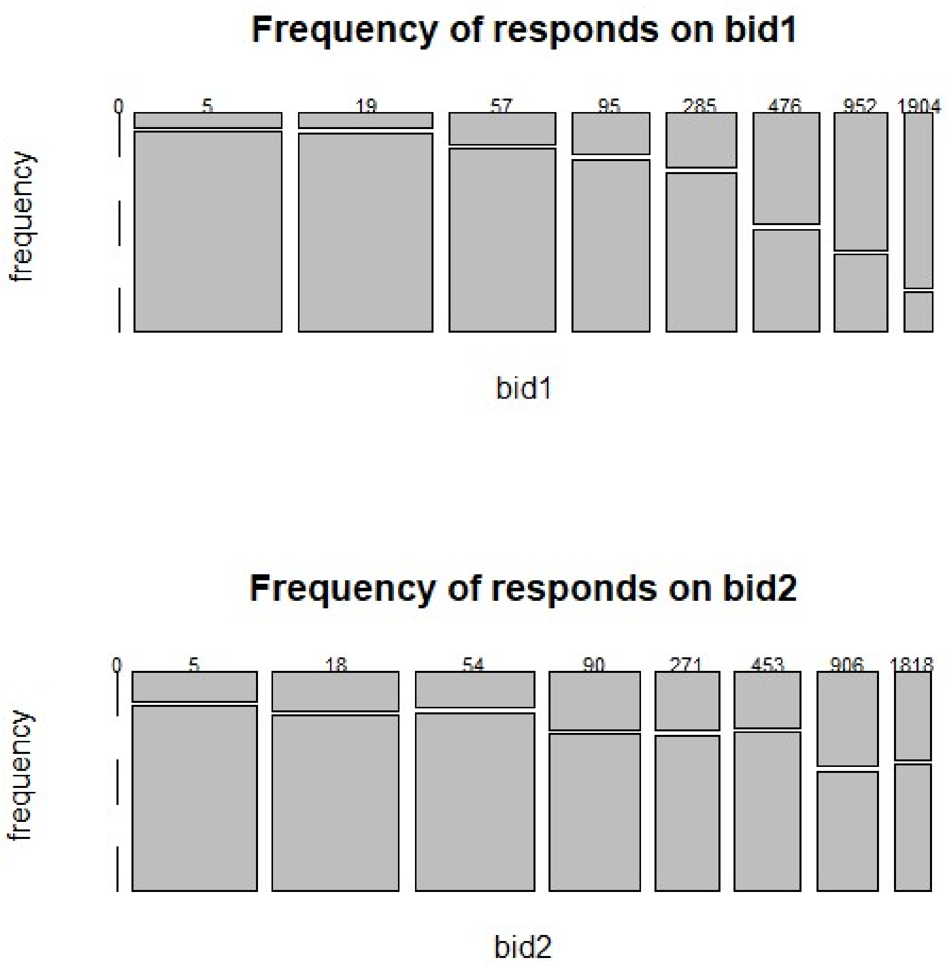


Figure 3.3: Response Summary of First Assigned Bid

Name	**Description**	**min**	**max**	**mean**	**S.E**
gtra	Agreement on “Average global temperature is increasing", 1-6 scale: 1, strongly disagree; 6, strongly agree	1	6	5.197	0.0294
Bid	The bid given to the respondents	5	1904	314.5	13.5821
geoegba	Agreement on “This geo-engineering project will benefit us”, 1-6 scale:1, strongly disagree; 6, strongly agree	1	6	4.045	0.032
inhospa	Dummy variable indicating whether admitted to hospital in the past 6 months: 1, yes; 0, no	0	1	0.027	0.005
expena	Respondents’ spending on merchandise which are used to reduce the side effect from pollution	0	20000	447.41	35.0796
watpa	Perception of risk from water pollution, 0-10 scale: 0, no risk at all; 10, extreme risk	0	10	8.629	0.0515
agea	Respondents’ age	16	75	32.7	0.2933
female	Respondents’ gender, 1 is female	0	1	0.5189	0.0156
mincomea	Respondents’ monthly income	1000	20000	6548	133.1741
ideologya	Respondents’ ideology, 1-5 scale: 1, very conservative; 5, very liberal	1	5	3.897	0.0280
intnewa	Respondents’ interest in news and public affairs, 1-4 scale: 1, barely interested; 4, most interested	1	4	1.925	0.0276

Table 3.1: Explanatory Variables

We are particularly interested in these three variables: geoegba, expena, and watpa. Firstly, the geo-engineering project is the hypothetical scenario within the WTP question design. respondents are told that the establishment of this project results in better environmental conditions. The more respondents believe that they gain benefit from the "geo-engineering" project, the more they are willing to say yes to the given bid and the more likely they are willing to pay. Secondly, the variable "expena" measures respondents' expenditure on pollution reduction products. It is believed that facing the same environmental conditions, the more respondents spend on these pollution reduction products, the more they are aware of the harm of pollution. Therefore, this variable should positively contribute to the WTP. Thirdly, "watpa" is one of the risk-scoring variables and it measures respondents' awareness or perception of risk from water pollution. The higher score they give to the risk, the more likely they are willing to pay for environmental improvement.

3.2.2 Hypotheses Testing

Prior to the WTP modelling, we were able to test the following hypotheses across the various types of models.

Firstly, we investigate the answers to WTP questions. It is expected that as the bid increases, the yes answer rate decreases. This is reflected in the model by the fact that the sign of the variable representing the bid (marked as variable "Bid" in the model) is negative. As the bid is highly related to the response, the estimation of the variable "Bid" should be significantly different from zero. Letting "β_{Bid}" be the name of the estimate, we can test the null hypothesis

H0: $\beta_{Bid} = 0$, against

H1: $\beta_{Bid} < 0$.

The expectation is that we reject the null hypothesis H0 and accept the alternative hypothesis H1 to see a negative sign before the variable "Bid".

Secondly, we hypothesise that the variable "geoegba", i.e. the belief that "the geo-engineering project will benefit us", will be a significant positive determinant of a yes answer and also upon the willingness to pay. Letting $\beta_{geoegba}$ be the estimated coefficient of the variable "geoegba", our interest is to test the null hypothesis

H0: $\beta_{geoegba} = 0$, against

H2: $\beta_{geoegba} > 0$.

We expect to accept the alternative hypothesis H2 and to find the variable "geoegba" has a positive coefficient. Furthermore, we are interested in investigating whether being recently hospitalised versus not being recently hospitalised is significant in relation to answers to WTP questions. Letting $\beta_{inhospa}$ be the estimated coefficient on variable "inhospa", we test the null hypothesis

H0: $\beta_{inhospa} = 0$, against

H3: $\beta_{inhospa} \neq 0$.

We expect null hypothesis H0 to be rejected and that the variable "inhospa" should have a positive effect on the probability of answering yes to the WTP questions.

Additionally, we can examine respondents' spending on products related to pollution. We believe that the variable "expena" is positively related to an answer of yes to the WTP question. Thus, we are interested in testing the null hypothesis that the estimated coefficient of the variable "expena", β_{expena}, is not significantly different from zero and to test if this variable has a positive effect on the dependent variables,

H0: $\beta_{expena} = 0$, against

H4: $\beta_{expena} > 0$.

The expectation is to reject null hypothesis H0 and accept the alternative hypothesis H4, concluding that spending on pollution reduction products positively affects participants' WTP.

Moreover, we take into account the fact that some people are interested in public affairs to a greater extent than others. To explore whether an interest in news and public affairs has an effect on the WTP question response, we test whether the variable "intewa" makes a difference in WTP outcomes. Letting β_{intewa} be the estimated coefficient on the variable "intewa", we test the null hypothesis

H0: $\beta_{intewa} = 0$, against

H5: $\beta_{intewa} \neq 0$.

What we anticipate from this test is to accept the alternative hypothesis H5.

The difference between the single and double bounded model is that the second-bounded model obtains more information from respondents, giving more information to the WTP bound (we expect that the WTP bound is narrower). We also expect that the WTP from double-bounded models is smaller than that from single-bounded ones. Denote the WTP from a single-bounded model by WTP_{single} and that from a double-bounded model by WTP_{double}, then we test the null hypothesis

H0: $WTP_{single} = WTP_{double}$, against

H6: $WTP_{single} > WTP_{double}$.

We expect that WTP_{double} is smaller than WTP_{single}, thus rejecting null hypothesis H0.

Finally, after the first two rounds, we can estimate the triple-bounded WTP. We expect the WTP from the double bounded model is greater than that in the triple bounded model. Letting triple-bounded WTP be WTP_{triple}, we test the null hypothesis

H0: $WTP_{double} = WTP_{triple}$, against

H7: $WTP_{double} > WTP_{triple}$.

3.3 Results and Discussions

Before we discussed estimation results, we want to investigate how respondents answer WTP questions. The eight bids designed for WTP via income tax in RMB are 5, 19, 57, 95, 285, 476, 952 and 1904. Before constructing the model, we investigated the number of respondents in each round along with yes/no answer distribution. The number of respondents should decrease along rounds and the proportion of yes answers is expected to be inversely related to the randomly assigned bid amount. Table 3.2 shows the detailed number of respondents in each round along with the eight bid levels. During round 1, 1028 respondents started

Term		Round 1		Round 2		Round 3		Round 4		Round 5		Round 6		Round 7	
Total	YES	1028	788	1005	634	741	419	496	251	299	138	169	64	85	23
	NO		240		371		322		245		161		105		62
5	YES	222	207	13	0	20	3	13	1	16	0	21	0	15	0
	NO		15		13		17		12		16		21		15
19	YES	202	188	224	188	19	6	19	3	24	3	7	0	13	2
	NO		14		36		13		16		21		7		11
57	YES	160	137	212	160	202	145	34	10	21	3	18	3	NA	NA
	NO		23		52		57		24		18		15		NA
95	YES	118	95	153	108	198	116	170	106	21	5	NA	NA	NA	NA
	NO		23		55		82		64		16		NA		NA
285	YES	106	79	148	65	136	76	133	67	100	66	NA	NA	NA	NA
	NO		27		83		60		66		34		NA		NA
476	YES	97	45	130	68	86	36	70	37	63	31	66	40	NA	NA
	NO		52		62		50		33		32		26		NA
952	YES	90	29	85	32	51	29	19	17	37	23	40	16	40	16
	NO		51		53		22		12		14		24		24
1904	YES	43	8	30	13	29	8	28	10	17	7	17	5	17	5
	NO		35		17		21		18		10		12		12

Table 3.2: Yes/No Distribution

the first round of the interviews, of which a total of 788 answered yes to the first given bid. Of the 1028 respondents, 222 were assigned to bid 5, 202 were assigned to bid 9, and 160 were assigned to bid 57. It can be seen that the total number of respondents decreased as the number of rounds increased. All 1028 respondents were involved in round 1, the number dropped to 1005 in round 2, and then to 741 in round 3. In round 4, the number of respondents was about half of the number in round 1.

	Round1	Round2	Round3	Round4	Round5	Round6
5	93.24%	0.00%	15.00%	7.69%	0.00%	0.00%
19	93.07%	83.93%	31.58%	15.79%	12.50%	0.00%
57	85.63%	75.47%	71.78%	29.41%	14.29%	16.67%
95	80.51%	66.26%	58.59%	62.35%	23.81%	0.00%
285	74.53%	43.92%	55.88%	50.38%	66.00%	0.00%
476	46.39%	52.31%	41.86%	52.86%	49.21%	60.61%
952	36.25%	37.65%	56.86%	58.62%	62.16%	40.00%
1904	18.60%	43.33%	27.59%	35.71%	41.18%	29.41%

Table 3.3: Summary of the probability of yes answer

Table 3.2 provides the number distribution, to which we now add Table 3.3, which gives the proportion of yes answers. The full sample probability distribution of yes answers across different bid amounts verifies the expectation that as the bid amount increases, the probability of yes answers decrease. For instance, the yes percentage to bid 5 (93.24%) is the highest and it is about twice that to bid 476 (46.39%) and is more than five times that of 1904 (18.6%). This serves as evidence for the rejection of null hypothesis H0. Figure 3.4 shows a visual representation

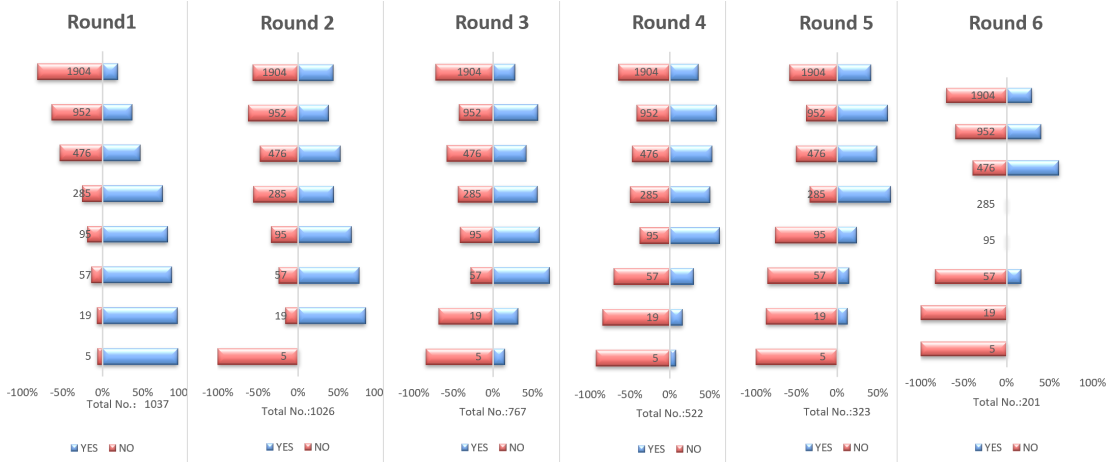


Figure 3.4: Proportion of Yes/No Answer in Each Round

of the yes/no distribution. The probability of the yes answer at bid 5 is 0, this situation does not hold for every database.

We also investigated the characteristics of respondents who would be willing to change their minds, preliminary analysis is reported in Appendix F.

3.3.1 Single-bounded DC Model Results

We ran the single-bounded DC model using the clean data. The single-bounded DC model is treated as a probit model when we assume WTP follows a normal distribution, with the dummy answers of the given bid being dependent variables, and variables in table 3.1 being independent variables. The results of this estimation are presented in Table 3.4.

Parameter	Coef.	Std. Err.	z	P> $\lvert z \rvert$
Intercept	-4.312e-01	5.253e-01	-0.821	0.4117
gtra	-4.312e-01	5.253e-01	0.699	0.4845
geoegba	2.600e-01	5.114e-02	5.085	3.68e-07 ***
inhospa	1.341	5.470e-01	2.451	0.0142 **
expena	1.204e-04	5.916e-05	2.036	0.0418 **
watpa	4.472e-02	3.090e-02	1.447	0.1478
agea	-7.409e-03	5.595e-03	-1.324	0.1854
female	-4.250e-02	1.041e-01	-0.408	0.6831
mincomea	4.413e-06	1.2386-05	0. 356	0.7215
ideologya	7.071e-02	5.726e-02	1.235	0.2168
intnewa	-1.092e-01	5.707e-02	-1.913	0.0557*
Bid	-1.648e-03	1.371e-04	-12.019	2e-16***
Mean WTP: 816.5614 (720.53, 941.66)				
observations = 980				

***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level

Table 3.4: Single-bounded DC Model Results

From the output of the probit model, we obtain coefficients associated to each one of the explanatory variables and the coefficient for the bid variable. We denote them as $\hat{\alpha}$ and $\hat{\delta}$ respectively and note that $\hat{\alpha} = \frac{\hat{\beta}}{\sigma}$, $\hat{\delta} = -\frac{1}{\sigma}$. So the estimation of β in (3.15) is $\hat{\beta} = -\frac{\hat{\alpha}}{\hat{\delta}}$. There are 980 samples involved in the single-bounded DC model, the results firstly show the coefficient of the variable "Bid" is negative and significantly different from zero at the significance degree 0.01, which indicates that when the bid amount increases, the probability of answering yes decreases. This result supports hypothesis H1.

It is expected that the respondents who think that they can benefit from "geo-engineering" project would be willing to pay more for an improvement of environmental quality, and people who have less belief in this project would pay less. The positive sign of variable "geoegba" verifies this expectation and supports hypothesis H2. The estimated coefficient of the variable "inhospa" is also significantly different from zero with a positive sign. It shows that being in hospitals affects people's willingness to pay. People who have been in hospital in the past 6 months are more likely to pay more for the improvement of the environment, serving as supporting evidence for hypothesis H3. We now focus on "expena", which indicates how much respondents spend on products designed to reduce the effects of pollution. The positive coefficient shows a strong positive impact on WTP and suggests that we accept hypothesis H4. According to our data set, the average annual expenditure on these products is 447.4118 and its 95% confidence interval is (378.5766, 516.2469). There is no need to buy these products unless having concern about pollution, so people are willing to pay more for these products for environmental improvements. Another significant variable in the single-bounded

DC model is “intnewa”, showing that ”being interested in news and public affairs” does affect WTP. Although it supports the hypothesis of non-zero estimation, it has a negative sign. It is expected that respondents more interested in public affairs would prefer to pay less. A possible explanation can be found in Rosenberg’s article (Rosenberg, 1962), which explains that public affairs are reflected in the interest shown in political matters. In the interviews, some respondents felt that it was the responsibility of the government, rather than the citizens, to take action to improve the environment.

Consistent with previous notation, letting X be the vector of explanatory variables, the expected value of WTP in a single-bounded DC model is $E(WTP) = X'\beta = X'[-\frac{\hat{\alpha}}{\hat{\delta}}]$. We find the mean WTP is 816.5614 RMB with 95% confidence interval from 720.53 to 941.66.

3.3.2 Double-bounded DC Model Results

Table 3.5 shows the estimation results of the double-bounded DC model. First, the model involves 964 observations, 16 of which were removed from the single-bounded DC model sample.

Parameter	Coef.	Std. Err.	z	P> $\|z\|$
gtra	67.80708	24.67116	2.75	0.006***
geoegba	99.35731	23.00167	4.32	0.000***
inhospa	316.1837	147.4526	2.14	0.032**
expena	0.0399321	0.0216899	1.84	0.066*
watpa	15.53919	14.12331	1.10	0.271
agea	-2.504727	2.478682	-1.01	0.312
female	12.12722	45.96146	0.26	0.792
mincomea	0.0189521	0.0056158	3.37	0.001***
ideologya	12.30361	25.82912	0.48	0.634
intnewa	-47.31785	25.77826	-1.84	0.066*
Intercept	-419.6127	237.11	-1.77	0.077*
Sigma	539.6347	23.31942	23.14	0.000***
WTP: 565.79 (517.14, 614.44)				
observations = 964				

***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level

Table 3.5: Double-bounded DC Model Result

The results from the double-bounded model are largely consistent with the single-bounded one. In addition, two other variables are also significant. The variable "gtra" measured respondents' agreement with the statement "Average global temperature is increasing" and is significantly different from zero at a 0.01% significance level. The positive sign of this variable in the double-bounded DC model indicates that the more respondents strongly believe the average global temperature is increasing, the more they would be willing to pay for environmental improvement. Also, the annual income has a positive effect on WTP since its estimation is also significantly different from zero, and the sign is positive. The significance and sign of the estimates on variable "geoegba", "inhospa", "expena", "intnewa" and "Bid" still support hypotheses 1-5.

The calculated mean WTP is 565.79 RMB with 95% confidence interval of 517.14 to 614.14. There is a noticeable drop of 277.29 from the WTP of the single-bounded DC model, moreover, the confidence intervals of mean WTPs from single bounded and double bounded formats are not overlapped, and the double-bounded estimate of the WTP interval is narrower. Data support H6.

3.3.3 Triple-bounded DC Model Results

The results of the triple-bounded model are presented in Table 3.6. There are 724 respondents in the triple bounded model. Most of the estimates are consistent with that of the double-bounded DC model. Hypotheses H1, H2, and H3 were still accepted in this model. Variable "inhospa" and "intnewa" are not statistically significant. The estimated WTP is 539.2712 with 95% confidence interval from

484.44 to 594.10. There is a small drop of 25.52 RMB to that in the double-bounded model, and their confidence intervals are largely overlapped. Therefore, we do not reject the null hypothesis and conclude that there is no statistical difference between the WTP estimates using double- and triple-bounded models.

Parameter	Coef.	Std. Err.	z	P> $\|z\|$
gtra	96.68736	28.32874	3.41	0.0016***
geoegba	121.1581	26.557	4.56	0.000***
inhospa	188.1175	166.356	1.13	0.258
expena	0.1179906	0.0347847	3.39	0.001***
watpa	-0.5115453	15.83594	-0.03	0.974
agea	-4.953179	2.897249	-1.71	0.087*
female	-1.137787	53.16875	-0.02	0.983
mincomea	0.0264627	0.0064837	4.08	0.000***
ideologya	31.24129	30.11614	1.04	0.300
intnewa	-41.14921	30.20242	-1.36	0.173
Intercept	-572.3698	268.6153	-2.38	0.017*
Sigma	572.3698	26.77723	21.38	0.000
WTP: 539.2712 (484.44, 594.10)				
observations = 724				

***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level

Table 3.6: Triple-bounded DC Model Results

Recalling the design of our WTP question and the interview process in Figure 2.1, the process stops when the answer changes from YES to NO or vice versa. During this process, we gathered more information to assess the respondent's true willingness to pay. The initial bid may be far from the respondent's true willingness to pay. Through the follow-up rounds of questions, the participants could encounter a value that is close enough to accept or large enough to reject. We recorded the final bid values which also terminated the elicitation process. Theoretically, an individual's true willingness to pay is between the maximum acceptable bid and the minimum unacceptable bid. The 95% CI of mean WTP from the double- and triple-bounded models largely overlapped within the terminated bid values. We take the mean of the terminated bid and conclude that the WTP

Item	Mean WTP	s.e	95% CI
Terminated bid	583.7271	20.66981	(543.1676, 624.2866)

Table 3.7: Average WTP of The Terminated Bid

from bid1 is 583.7271 with 95% confidence interval (543.1676, 624.2866). This value is between the double-bounded WTP and triple-bounded WTP estimates.

Methods for Determining Confidence Interval

There are several ways to compute confidence intervals (CI) for WTP estimates. The delta method is the most common method when calculating the standard error of a function. It uses the first-order Taylor series of the function. Suppose the function of interest is dependent on a vector of n variables $X = (x_1, x_2, x_3, \ldots, x_n)$ and a parameter vector $\hat{\beta} = \hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_n$ is $F(X, \hat{\beta}) = X\hat{\beta}$. Then the first order

Taylor series is

$$F(X,\hat{\beta}) \approx F(\overline{X}\hat{\beta}) + \nabla F(\overline{X}\hat{\beta})^T \cdot (X\hat{\beta} - \overline{X}\hat{\beta}), \tag{3.33}$$

where $\overline{X}$ is the vector of the mean values of X, $\nabla F(\overline{X}\hat{\beta})^T$ is the transpose of the partial derivatives of $F(X,\hat{\beta})$.

The variance of the function is

$$\operatorname{var} F(X,\hat{\beta}) = \nabla F(X\hat{\beta})^T \cdot \Sigma(\hat{\beta}) \cdot \nabla F(X\hat{\beta}), \tag{3.34}$$

where $\Sigma(\hat{\beta})$ is the covariance matrix of $\hat{\beta}$. The standard error is the square root of the variance, that is $se(X,\hat{\beta}) = \sqrt{\operatorname{var} F(X,\hat{\beta})}$. The confidence interval at confidence level $1-\alpha$ is given by

$$F(\overline{X}\hat{\beta}) \pm z(\alpha/2) * s.e.(X,\hat{\beta}). \tag{3.35}$$

The delta method assumes the model follows a normal distribution and gives a symmetric confidence interval.

Other methods, such as the bootstrap method and the Krinsky and Robb method (Krinsky and Robb, 1986), are very similar because they use simulation to calculate the standard error. The variance is obtained by estimating the simulated models on different data samples. Each data sample is obtained by replacing the original N observations. The procedure can be described as follows:

1. Get the estimates of interest on the original sample of data $\hat{\beta}$.

2. Calculate the predicted values $F_i(X, \hat{\beta})$ $(i = 1, 2, \dot{;} n)$ and the corresponding residual terms u_i.

3. For each observation i, find a replacement of $F_i(X, \hat{\beta})$ to create a repeated sample of the data set which must reflect the original sampling process. This process can be achieved by creating a new residual u^* which follows the same distribution of the original data. Thus the new replacement is $F_i^*(X, \hat{\beta}) = F_i(X, \hat{\beta}) + u^*$. The new data set is the combination of the new F_i^* and the original values of X_i.

4. Estimate the new model with the replacement to obtain the new estimates and the new predicted values.

5. Repeat steps 2–4 n times.

6. Get the newest estimates and standard error.

Tables 3.8 and 3.9 present the confidence intervals calculated by the delta and bootstrap methods for the double- and triple-bounded models respectively.

Method	Mean WTP	Std. Err.	z	P> $\|z\|$	95 % CI
Delta method	565.7901	24.82112	22.79	0.000	(517.1416, 614.4386)
Bootstrap	565.7901	34.75838	16.28	0.000	(497.6649, 633.9152)

Table 3.8: Bootstrap CI and Delta CI of Double-bounded Model

The bootstrap method does not make a bid difference to WTP estimations. The obvious difference is seen in the standard error of the WTP estimations.

Testing of the Multiple Rounds Effect Using the Traditional Maximum Likelihood Estimation Method

Method	Mean WTP	Std. Err.	z	P> $\|z\|$	95 % Confidence Interval
Delta method	539.2712	27.97486	19.28	0.000	(484.4415, 594.1009)
Bootstrap	539.2711	32.88686	16.40	0.000	(474.814, 603.7282)

Table 3.9: Bootstrap CI and delta CI of Triple-bounded Model

Table 3.10 lists the estimated mean WTP from the three models and the confidence intervals from both the delta and bootstrap methods. Figure 3.5 visually shows WTP estimations with confidence intervals. From table 3.10 and

Model	Delta Method		Bootstrap Method	
	WTP	CI	WTP	CI
Sigle-bounded	816.56	(720.53, 941.66)	816.56	(659.17, 936.67)
Double-bounded	565.79	(517.14, 614.44)	565.79	(497.66, 633.92)
Triple-bounded	539.27	(484.44, 594.10)	539.27	(474.81, 603.73)

Table 3.10: WTP Estimates from Three Rounds

figure 3.5, we can draw the following conclusions. (1) There is no overlap in the confidence interval between single-bounded and double-bounded WTP estimates, which indicates the WTP behaviour is totally different across these two rounds. However, we do not find significant evidence of differences in double-bounded and triple-bounded WTP estimates; (2) The WTP from single bounded procedure is significantly different from that of double bounded and triple bounded procedures, while the WTP from triple bounded is not statistically different from that of double-bounded procedure; (3) The estimated WTP dropped by 30% from the first round to the second round, but only by 4.6% from the second round to the third round; (4) It further reveals that respondents have different WTP patterns for round one and round two. They will not reveal true WTP until further infor-

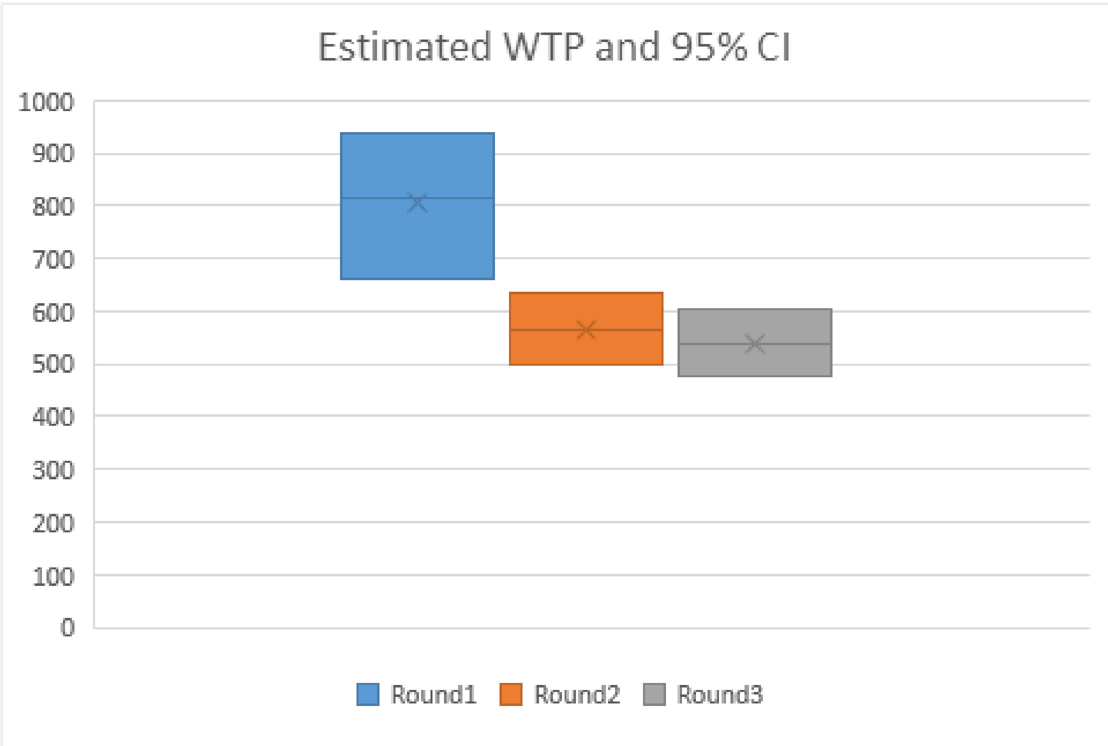


Figure 3.5: WTP Estimates from Three Rounds

mation is applied; (5) Although there is no significant difference between WTP in round two and round three, with more information included, the confidence interval is narrower, showing that the estimate is more reliable.

Moreover, the widths of interval in the single-bounded model for the delta and bootstrap methods are 221.13 and 277.5, respectively. The width in the double bounded model for the delta and bootstrap methods are 97.3 and 136.26 which are much smaller than those in the single bounded model. In the triple bounded model, the lengths are 106.66 and 128.92, respectively. The same pattern maintains in the double-bounded model. To briefly summarise, the bootstrap method produces wider confidence intervals.

Chapter 4

Testing of Multiple Rounds Effect using Markov Chain Monte Carlo Method

4.1 Introduction to Markov Chain Monte Carlo Method

4.1.1 Introduction to MCMC

It is very common that data in the statistical and econometric models are related to binary and multivariate responses. We have applied the maximum likelihood estimation (MLE) method to find out respondents' willingness to pay in single-, double- and triple-bounded dichotomous choice models. We are interested in whether classical MLE methods give estimates close to the true value, i.e., whether the WTP is close to the true WTP. A number of studies have shown that larger sample sizes provide more information and result in more accurate estimates (Asiamah, Mensah, and Oteng-Abayie, 2017). To address the problem of limitation on samples of MLE estimation, this chapter uses a Markov chain Monte Carlo (MCMC) method with Gibbs sampling approach to simulate the parameters of the Bayesian probit model for the single-bounded data, as well as other Bayesian models for the double- and triple-bounded data.

The Monte Carlo method relies on repeated random sampling to obtain numerical results. The key part of the Monte Carlo method is to get the probability distribution of a matrix, x. So, if we know the probability distribution of x, we can generate n sets of samples from x based on the probability distribution by simulating the sample and calculating the probability. For simple distributions, we can easily generate more data sets using standard statistical software. However, in practice, the distributions needed may be more complex. To solve the problem of getting sample sets with complex probability distributions, we implement Markov chains.

In a Markov chain, we assume that the probability of a state at a given moment $t+1$ depends only on its previous state at t, which we may express as

$$P(X^{t+1} \mid X^1, \cdots, X^t) = P(X^{t+1} \mid X^t). \tag{4.1}$$

We are interested in whether a Markov chain would give an accurate prediction of respondents' true WTP. In our case, the interviewers kept asking respondents questions about their willingness to pay until their answers changed. So, before termination, every answer can be regarded as being dependent upon the previous answer.

Markov chain transition probability matrices can converge to a stable probability distribution. This means that MCMC can simulate the high-dimensional probability distribution of a Markov chain. When, after the burn-in period (Meyn and Tweedie, 2012), MCMC can eliminate the influence of the initial parameters and reach a steady state, a simulation sample can be generated for each state transition (Sugden, 1999).

The following steps are implemented to carry out the method.

1. Input Markov chain state transition matrix P, set the threshold number of state transition times t and the number n of samples to be generated.
2. An initial state value of x_0 is obtained from any sample probability distribution of the original data set.
3. For $i = 0$ to $n - 1$, obtain x_{i+1} from the conditional probability distribution $P(x_{i+1} \mid x_i)$.
4. Repeat step 3 and get $(x_1^{(t)}, x_2^{(t)}, \cdots, x_n^{(t)})$.
5. Use the new set to run the models.

The first step is about setting our target. In the second step, we use information from our existing data set to get an initial state value. The MCMC approach is therefore mainly concentrated in steps three and four, where a new sample set is updated through the MCMC procedure.

4.2 Bayesian Probit Regression Using Latent Variable with MCMC Gibbs Sampling Procedure

4.2.1 Probit Regression Model with Latent Variable

Albert and Chib (Albert and Chib, 1993) demonstrated a latent variable model (or auxiliary model) in 1993 for a Bayesian dichotomous regression model in connection with an MCMC simulation. This approach makes the conditional distribution of the model parameters equivalent to that under a Bayesian normal linear regression model with Gaussian noise (Holmes and Held, 2006), in which case the conjugate priors can be used as conditional likelihood. In this thesis, we first construct a latent variable method to see if the simulated parameter is responsible for WTP results.

In our project, when respondents were asked if they would be willing to pay a certain amount of money in exchange for a good environment, they would provide a dichotomous answer “yes” or “no”. The model was designed to estimate the probability that a sample with a particular characteristic or attribute (independent factor) will fall into a particular dichotomous response. If we note y as the dichotomous response, for respondent i,

$$y_i = \begin{cases} 1 & \text{YES}, \\ 0 & \text{NO}. \end{cases} \tag{4.2}$$

As discussed, y_i follows a Bernoulli distribution with probability of answering "YES" p_i. Define the binary regression model as

$$p_i(y_i) = F(X_i^T \beta + \varepsilon_i), \tag{4.3}$$

where β is a vector of unknown parameters, X is the vector of known covariates and F is the c.d.f. linking the probability p_i with the linear structure $X_i\beta$. The probit model is obtained if F is the standard Gaussian c.d.f., that is

$$p_i(y_i) = \Phi(X_i^T \beta + \varepsilon_i), \tag{4.4}$$

where Φ is the c.d.f. of the standard normal distribution, of which the inverse is the probit link function. According to the RUM assumption, the probability of a respondent responding "YES" to a given bid value B is

$$\begin{aligned} Pr(YES) &= Pr(y = 1 \mid B) \\ &= Pr(X_i^T \beta + \varepsilon_i > 0) \\ &= Pr(\varepsilon_i < X_i^T \beta) \\ &= \Phi(X_i^T \beta) \end{aligned} \tag{4.5}$$

we may also write (4.4) as

$$\Phi^{-1}(y_i) = X_i^T\beta + \varepsilon_i. \tag{4.6}$$

If we introduce a variable Z to represent $\Phi^{-1}(y)$, this model becomes a latent variable model where z is a continuous latent variable. Now, we introduce the independent latent variables Z into the model, where z_i is distributed $N(x_i^T\beta, 1)$ and has the following relationship with the dichotomous dependent variable y_i,

$$y_i \begin{cases} 0 & \text{if } z_i \leq 0, \\ 1 & \text{if } z_i > 0. \end{cases} \tag{4.7}$$

This approach connects the probit regression model on the y_i with the normal linear regression model on the latent variable z_i,

$$z_i = X_i^T\beta + \varepsilon_i. \tag{4.8}$$

Since the samples are independent and identically distributed, the joint likelihood of total samples is equal to the likelihood of any single sample

$$L(\beta \mid z_i, X) = \prod_{i=1}^{n}(\Phi(X_i\beta)^{z_i}[(1-\Phi(X_i\beta)^{1-z_i})]), \tag{4.9}$$

taking the log of each side, the log-likelihood function is

$$\ln L(\beta \mid z_i, X) = \sum_{i=1}^{n}(z_i(\ln\Phi(X_i\beta) + [(1-z_i)\ln(1-\Phi(X_i\beta))])). \tag{4.10}$$

4.2.2 Derivation of Posterior Distribution

The MCMC method is based on Bayesian statistics, in which rather than assuming that the parameters are fixed, we regard them as random variables. In this method, posterior distributions of the parameters are what we are interested in as they can be derived from prior distributions.

Assume we have a model with parameter β and a corresponding probability density function (pdf) $p(\beta)$, which is exactly the prior distribution of β. With the observed attributes data matrix X, the joint pdf of the data and the parameters $p(X, \beta)$ is given by Bayesian Theorem,

$$\begin{aligned} p(X, \beta) &= p(X \mid \beta)p(\beta) \\ &= p(\beta \mid X)p(X). \end{aligned} \tag{4.11}$$

The posterior distribution of β is the distribution of β given X, that is $p(\beta \mid X)$, which we may write as

$$\begin{aligned} p(\beta \mid X) &= p(X, \beta)/p(X) \\ &= p(X \mid \beta)p(\beta)/p(X). \end{aligned} \tag{4.12}$$

Since $p(X)$ is independent of β, (4.12) can also be written as

$$p(\beta \mid X) \propto p(X \mid \beta)p(\beta), \tag{4.13}$$

where $p(X \mid \beta) = L(\beta \mid X)$. The probability is also the likelihood function. So we see that (4.13) is also expressed as

$$p(\beta \mid X) \propto likelihood \times prior. \tag{4.14}$$

After we introduce a latent variable z_i, y_i becomes deterministic conditional on the sign of the latent variable z_i where z_i follows a normal distribution. The joint posterior distribution of the latent variables z_i and parameters β is

$$\begin{aligned} p(Z, \beta \mid Y, X) &\propto p(\beta)p(Z \mid \beta, X)p(Y \mid Z) \\ &= p(\beta)\prod_{i=1}^{n} p(z_i \mid \beta, x_i)p(y_i \mid z_i), \end{aligned} \tag{4.15}$$

where we have

$$p(z_i \mid \beta, x_i) = \mathcal{N}(z_i \mid x_i\beta, 1), \tag{4.16}$$

$$p(y_i \mid z_i) = \begin{cases} y_i = 0 & \text{if } z_i \leq 0, \\ \\ y_i = 1 & \text{if } z_i > 0. \end{cases} \tag{4.17}$$

This joint posterior in (4.15) is not easy to normalise and sample from directly, so we introduce Gibbs sampling. Gibbs sampling is used in the cases where the posterior contains multi-dimensional parameters. For this, we need only compute the marginal posterior of the parameters β and z_i. So in Gibbs sampling, we only need to get the conditional distribution of β which is $p(\beta \mid Z, Y, x) = p(\beta \mid Z, , x)$ as β is conditionally independent of Y given Z, and the conditional distribution of z, which is $p(z \mid \beta, Y, X)$. The full conditional distribution of β is given by

$$p(\beta \mid Z, X) \propto p(\beta) \prod_{i=1}^{n} \mathcal{N}(z_i \mid x_i\beta, 1). \tag{4.18}$$

If we assign a prior for β, with the condition $p(\beta) \propto 1$, i.e. when a uniform prior is chosen for β, then

$$\beta \mid Z, X \sim \mathcal{N}((X^T X)^{-1} X^T Z, (X^T X)^{-1}), \tag{4.19}$$

where $(X^T X)^{-1} = I(\hat{\beta}^{-1})$ and I is the observed information matrix. if we assume $p(\beta) \sim \mathcal{N}(\beta_0, S_0)$, then

$$\beta \mid Z, X \sim \mathcal{N}(\mathbf{B}, \mathbf{V}), \tag{4.20}$$

where

$$\mathbf{B} = \mathbf{V}(S_0^{-1}\beta_0 + X^T Z), \tag{4.21}$$

$$\mathbf{V} = (S_0^{-1} + X^T X)^{-1}. \tag{4.22}$$

We have noted that z_i follows a normal distribution on β and X, which is $\mathcal{N}(x_i\beta, 1)$. However, we now also need to take y_i into consideration, which ensures that z_i follows a truncated normal distribution,

$$z_i \mid \beta, y_i, x_i \propto \begin{cases} \mathcal{TN}(x_i, 1, 0, \infty) & \text{if } y_i = 1 \\ \mathcal{TN}(x_i, 1, -\infty, 0) & \text{if } y_i = 0. \end{cases} \tag{4.23}$$

The derivation process of equations (4.20), (4.21) and (4.22) is given in Appendix G.

4.2.3 Gibbs Sampling Procedure

Gibbs sampling is uniquely positioned to deal with sampling from intractable distributions as it allows one to compute marginal distributions of many parameters instead of working on the intractable joint posterior distribution. Thus, it is suitable for multinomial, multivariate and hierarchical data. The algorithm below shows how this could be generalised in a straightforward manner to simulate the posterior distribution of the regression parameters.

1. Set initial value to parameters β. The initial values are from the results of single-bounded CVM.
2. Draw z_i conditional on β and y_i using a truncated normal distribution which is expressed in (4.23).
3. Draw β conditional on z_i and X using the distribution in (4.19). Suppose we have p variables, the algorithm starts by simulating $\beta_1^{(1)}, \beta_2^{(1)}, \cdots, \beta_p^{(1)}$, this is a repeated process and iterates t times until generating the sample $\beta^{(t)} = (\beta_1^{(t)}, \beta_2^{(t)}, \cdots, \beta_p^{(t)})$.
4. Repeat the sampling route in steps (2) and (3) 10000 times with the first 5000 times as a burn-in period.
5. Obtain β and analyse its properties.

4.2.4 Holmes and Held Extension

There is a potential problem with MCMC simulation in that there may exist a correlation between the parameters β and latent variable or auxiliary variable Z, which may lead to slow mixing of the chain, Andreas (Kapourani, 2019) provided an idea of using Holmes and Held extension. Holmes and Held (Rue, Martino, and Chopin, 2009) suggested a simple methodology to reduce the autocorrelation in the MCMC algorithm that exists in the method proposed by Albert and Chib (Albert and Chib, 1993) by updating β and Z jointly with the following factorisation:

$$p(z, \beta \mid y, X) = p(\beta \mid z, X)p(z \mid y, X), \tag{4.24}$$

where $p(\beta \mid z, X)$ remains unchanged while z is now updated by integrating its marginal distribution over β,

$$\begin{aligned} p(z \mid y, X) &\propto p(y \mid z, X)p(z \mid X) \\ &= p(y \mid z, X) \int_\beta p(z \mid X, \beta)p(\beta)\, d\beta \\ &= \mathcal{N}(0, I_N + XVX^T)\, \mathrm{Ind}(y, z). \end{aligned} \tag{4.25}$$

where $\mathrm{Ind}(y, z)$ is the indicator function which truncates the multivariate normal distribution of z. Assume that the prior distribution of β is a mean zero distribution, $N(0, S_0)$, then the distribution of $p(z \mid y, X)$ is:

$$p(z \mid y, X) \propto N(0, I_N + XS_0X^T)\, \mathrm{Ind}(y, z), \tag{4.26}$$

It is known that direct sampling from a truncated multivariate normal distribution is difficult, Holmes and Held (Holmes and Held, 2006) claim that it is straightforward to use a Gibbs sampling algorithm,

$$z_i \mid \boldsymbol{z}_{-i}, y_i, \boldsymbol{x}_i \sim \begin{cases} \mathcal{TN}\left(b_i, v_i, 0, \infty\right) & \text{if } y_i = 1, \\ \mathcal{TN}\left(b_i, v_i, -\infty, 0\right) & \text{if } y_i = 0, \end{cases} \tag{4.27}$$

where b_i and v_i are the means and variances obtained from the leave-one-out marginal predictive densities (Vehtari et al., 2016). The parameters m_i, v_i and w_i can be calculated using the method suggested by Henderson and Searle (Henderson and Searle, 1981) to obtain

$$b_i = x_i B - w_i(z_i - x_i B), \tag{4.28}$$

$$v_i = 1 + w_i, \tag{4.29}$$

$$w_i = h_i/(1 - h_i), \tag{4.30}$$

where h_i is the diagonal element of the Bayesian hat matrix $x\left(V_\beta^{-1} + x^T x\right)^{-1} x^T$, $h_i = (\boldsymbol{H})_{ii}, \boldsymbol{H} = \boldsymbol{X}\boldsymbol{V}\boldsymbol{X}^T$, and z_i is the current value for z_i, $B = \left(V_\beta^{-1} + x^T x\right)^{-1} x^T z$.

After updating the value of z_i, we recalculated the posterior mean $\boldsymbol{B}$ using the relationship,

$$\boldsymbol{B} = \boldsymbol{B}^{old} + \boldsymbol{S}_i(z_i - z_i^{old}) \tag{4.31}$$

where $\boldsymbol{B}^{old}$ and z_i^{old} denote the values of $\boldsymbol{B}$ and z_i prior to the update of z_i, and $\boldsymbol{S}_i$ denotes the ith column of $\boldsymbol{S} = \boldsymbol{V}\boldsymbol{X}^T$.

4.2.5 Results and Discussion of Probit Model

Parameter Estimation

Table 4.1 presents the simulated estimations of the single-bounded MCMC procedure with the Albert and Chibs Method (ACM). The result is not as initially expected. Firstly, using this we cannot verify any of hypotheses 1–5 in Chapter three, because none of the variables is significantly different from zero. Secondly, the signs of the parameters are also opposite to what we expected except for variables "age" and "Bid". However, as these two variables are not significant, they do not have an effect on the ultimate result. Additionally, the mean WTP is 1193.262 RMB, much more than we saw in Chapter three for the single-bounded model (816.56), and not even in its 95% confidence interval. Let us look at the estimation result from the Holmes and Held method (HHM), which is presented in Table 4.2.

Parameter	Coef.	Std. Err.	t	P> $\|t\|$
Intercept	0.0865	0.9999	0.0979	0.9220
gtra	-0.0069	0.9931	-0.02560	0.9796
geoegba	-0.0166	1.0072	0.0077	0.9939
inhospa	-0.0062	0.9935	0.0008	0.9994
expena	0.0092	0.9948	0.0057	0.9954
watpa	0.0228	0.9909	0.0214	0.1478
agea	-0.0058	0.9892	0.0113	0.9909
female	-0.0148	0.9960	0.0160	0.9873
mincomea	-0.0001	0.9929	0.0026	0.9979
ideologya	-0.0035	1.0082	-0.0101	0.9919
intnewa	0.0202	0.9915	0.0002	0.9998
Bid	-0.0030	1.0029	-0.0020	0.9984
Mean WTP: 1193.262				

***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level

Table 4.1: Single-bounded MCMC Estimations with Albert and Chibs Method

Parameter	Coef.	Std. Err.	t	P> $\|t\|$
Intercept	-4.5193 e-01	5.1950 e-01	-0.8699	4.0433 e-01
gtra	3.8947 e-02	5.6488 e-02	0.6895	5.0930 e-01
geoegba	2.6514 e-01	5.1185 e-02	5.1801	1.8684 e-07 * * *
inhospa	1.4262 e-00	5.4145 e-01	2.6340	8.9763 e-03 * * *
expena	1.2722 e-04	6.0231 e-05	2.1123	4.1006 e-02 * *
watpa	4.5854 e-02	3.0999 e-02	1.4793	1.4573 e-01
agea	-7.4404 e-03	5.6427 e-03	-1.3186	1.7563 e-01
genda	-4.1757 e-02	1.0489 e-01	-0.3982	6.8250 e-01
mincomea	4.5662 e-06	1.2392 e-05	0.3685	7.1920 e-01
ideologya	7.1718 e-02	5.8030 e-02	1.2359	2.1561 e-01
intnewa	-1.1066 e-01	5.6983 e-02	-1.9419	5.5903 e-02 *
BID	-1.6763 e-03	1.2981 e-04	-12.9121	5.4124 e-38 * * *
Mean WTP: 787.7065				

***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level

Table 4.2: Single-bounded MCMC Estimations with Holmes and Hold Method

In this thesis, the Holmes and Held method produces better results than the Albert and Chibs method. Firstly, the coefficient of the variable "Bid" is negative and significantly different from zero at the significance level of 0.01, which indicates that when the bid amount increases, the probability of answering yes also decreases. This result is consistent with the significance of the probit MLE model in Chapter three and supports hypothesis H1. Also, as in the probit MLE model, the positive sign and significance of the estimate of the variable "geoegba" verify the hypothesis H2. The estimated coefficient of the variable "inhospa" is also significantly different from zero with a positive sign. In the MCMC probit model, its significance is improved from 0.05% level to 0.01% level, providing more evidence for hypothesis H3. Hypothesis H4 is supported by the estimate of the variable "expena" and hypothesis H5 is supported by the estimate of the variable "intenewa". Overall, the number and sign of significant variables are the same as in the classical MLE probit model, which suggests that MCMC methods produce consistent results with MLE methods. Using $E(WTP) = X'\beta = X'[-\frac{\hat{\alpha}}{\hat{\delta}}]$, we find that the mean WTP is 787.7065 RMB, which lies within the 95% confidence interval from 720.53 to 941.66 of the WTP from the MLE method.

Convergence Checking

To explore why the Albert and Chibs method does not give significant results after simulation, we need to investigate convergence situations. When the MCMC program is applied, it needs to determine whether the sample size is large enough to estimate the parameters of interest from the distribution. The rate of convergence of the algorithm is one of the obstacles when using the MCMC process. Only the converged process could produce satisfactory results. According to Sinharay (Sinharay, 2003), what makes the convergence to many users of MCMC is that it is not that of a scalar quantity to a point, but that of a distribution to another distribution. Some researchers have found some useful diagnostic tools to assess the convergence of the MCMC program while researchers like Cowles and Carlin (Cowles and Carlin, 1996) demonstrated that a single converge diagnostic tool is not enough for a successful convergence process. A combined use of strategies is recommended to accelerate MCMC sampler convergence. To have a better understanding of the usage, illustrative reviews of existing essential diagnostic tools are required. In this chapter, we aim to first introduce existing diagnostic tools and then use some of them to detect the convergence of the program in our project.

The first tool for checking convergence is the Effective Sample Size (ESS). When referring to time series (including Markov chains), the ESS gives an estimate of the size of independent iterations of the distribution of parameters in the Markov chain. The formula for the ESS is given by,

$$ESS = \frac{M}{\tau} = \frac{M}{1 + 2\sum_{k=1}^{\infty} \rho_k(x)} \tag{4.32}$$

where $\rho_k(x)$ is the autocorrelation at lag (*Autocorrelation Function* n.d.) k for variable x, and τ is called the autocorrelation time. ESS and τ are inversely proportional to each other, low ESS or high τ indicates bad mixing of the Markov chain, and leading posterior means may be unreliable. The ESS of each variable of ACM and HHE is given in Table 4.3. Table 4.3 shows that the variables for the

	var1	var2	var3	var4	var5	var6	var7	var8	var9	var10	var11	var12
ACM	5000	5697	4477	5303	5000	5000	5295	4758	5000	5000	5000	5000
HHE	3050	2589	2598	890	1504	2965	2786	2611	2606	2669	2871	2078

Table 4.3: ESS Comparison Between Two Probit Methods

Albert and Chibs method require a larger sample size to achieve convergence, with 10 out of 12 variables converging after 5000 repeats. The Holmes and Held method has higher efficiency, with 5000 repetitions being enough for the convergence of all variables. To get the posterior mean with the same accuracy, the number of draws must be increased when applying the Albert and Chibs method.

The second tool for checking convergence is through the visual trace plots. Following Andreas's (Kapourani, 2019) idea of drawing distribution and chain values of parameters, we make two types of plots. At the top, we have histograms of distributions of estimations after the burn-in period, at the bottom panel we see the chain values of the parameters along the MCMC simulation. We plot the estimations from ACM and HHE separately and we display four significant parameters as examples, "geoegba", "inhospa", "intnews" and "Bid", see Figure 4.1, Figure 4.3, Figure 4.2 and Figure 4.4. The plots for the other parameters are put in Appendix H.

On the aforementioned plots, the red colour indicated the values of ACM estimates, the blue indicates HHE estimates and the green indicates MLE estimates. In the plots of ACM estimates, we set ACM estimates as the baseline, in the plots of HHE estimates, we set HHE estimates as the baseline. We can make the following observations based on these plots. Firstly, HHE estimates have

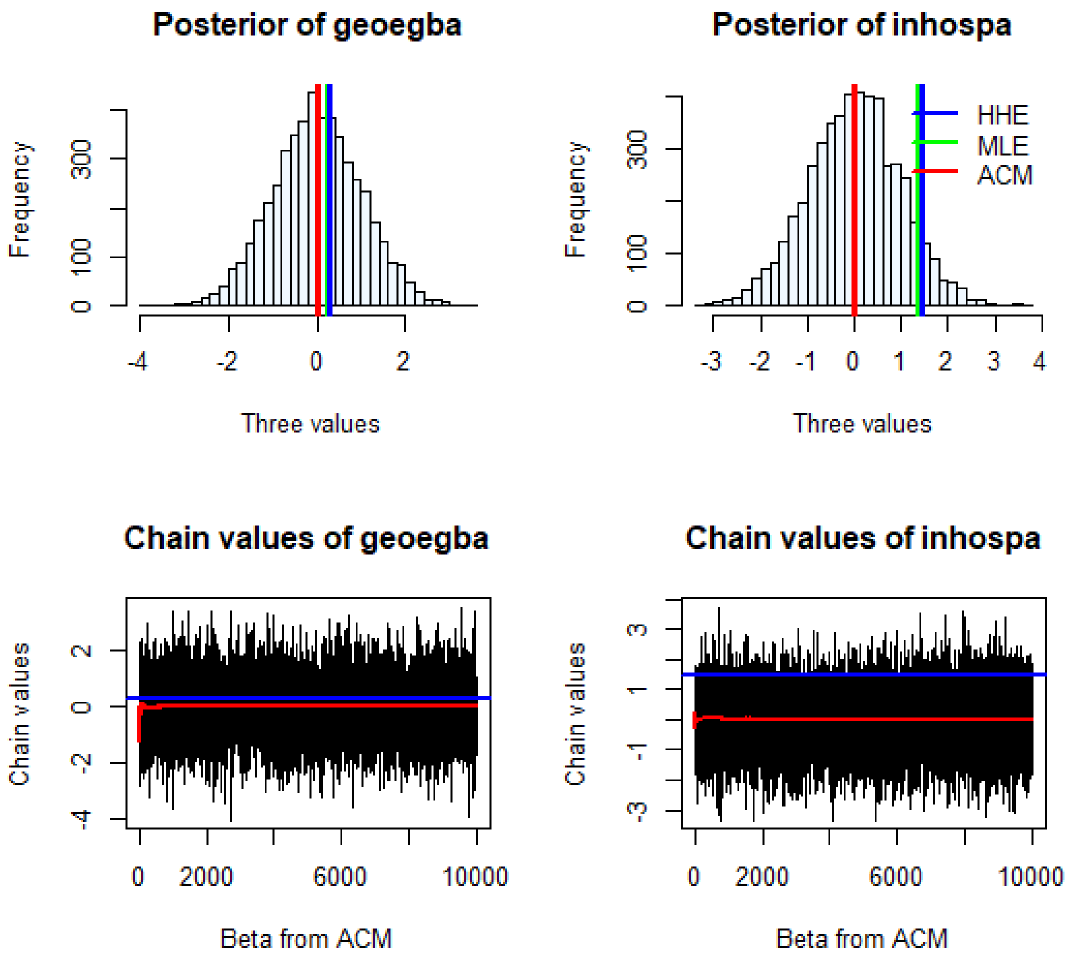


Figure 4.1: Parameter geoegba and inhospa from ACM

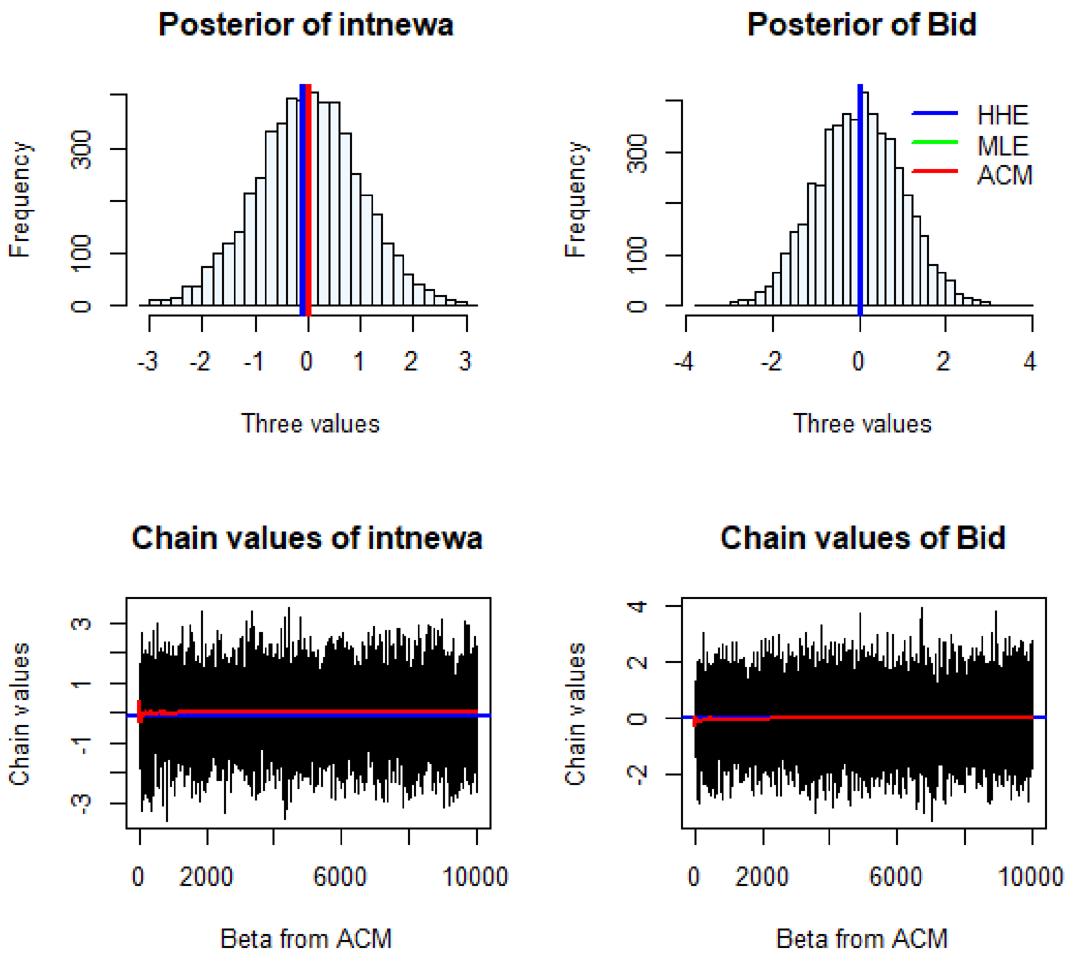


Figure 4.2: Parameters intnews and Bid from ACM

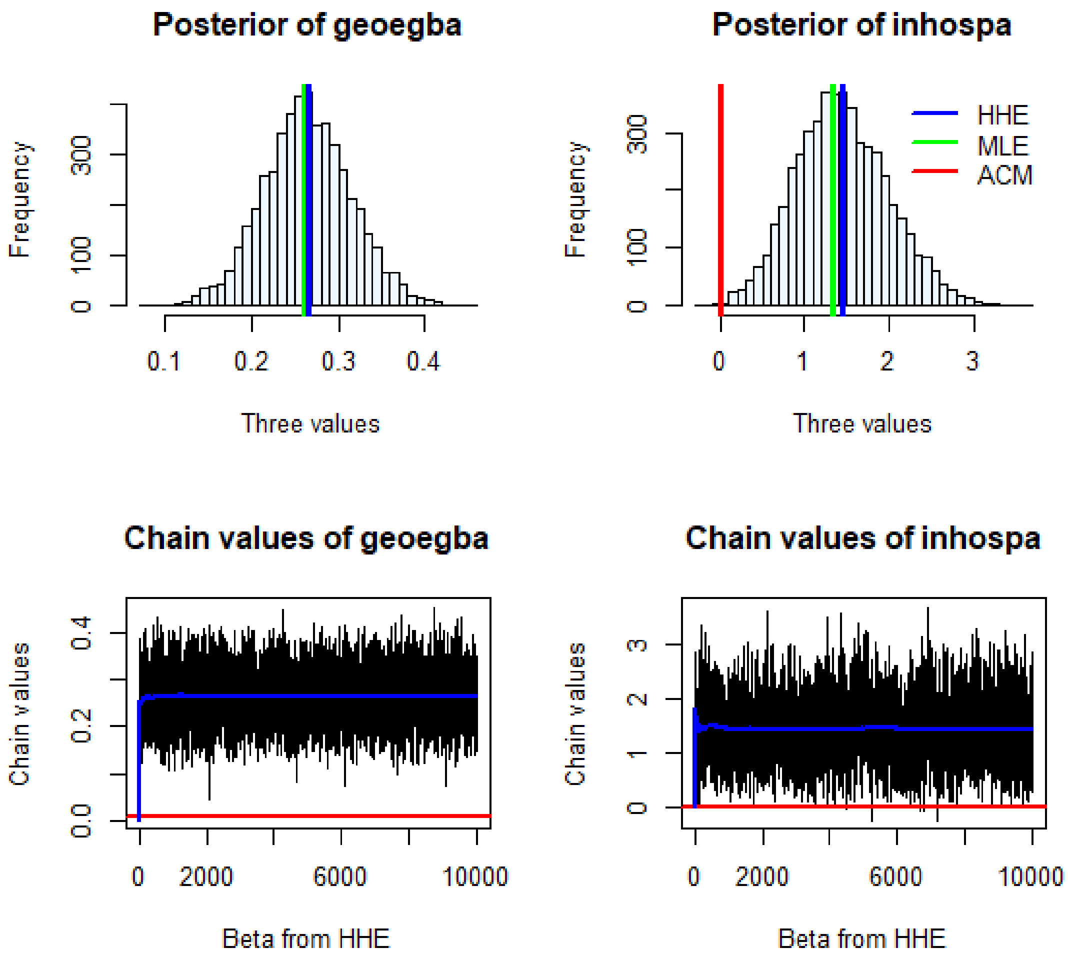


Figure 4.3: Parameters geoegba and inhospa from HHE

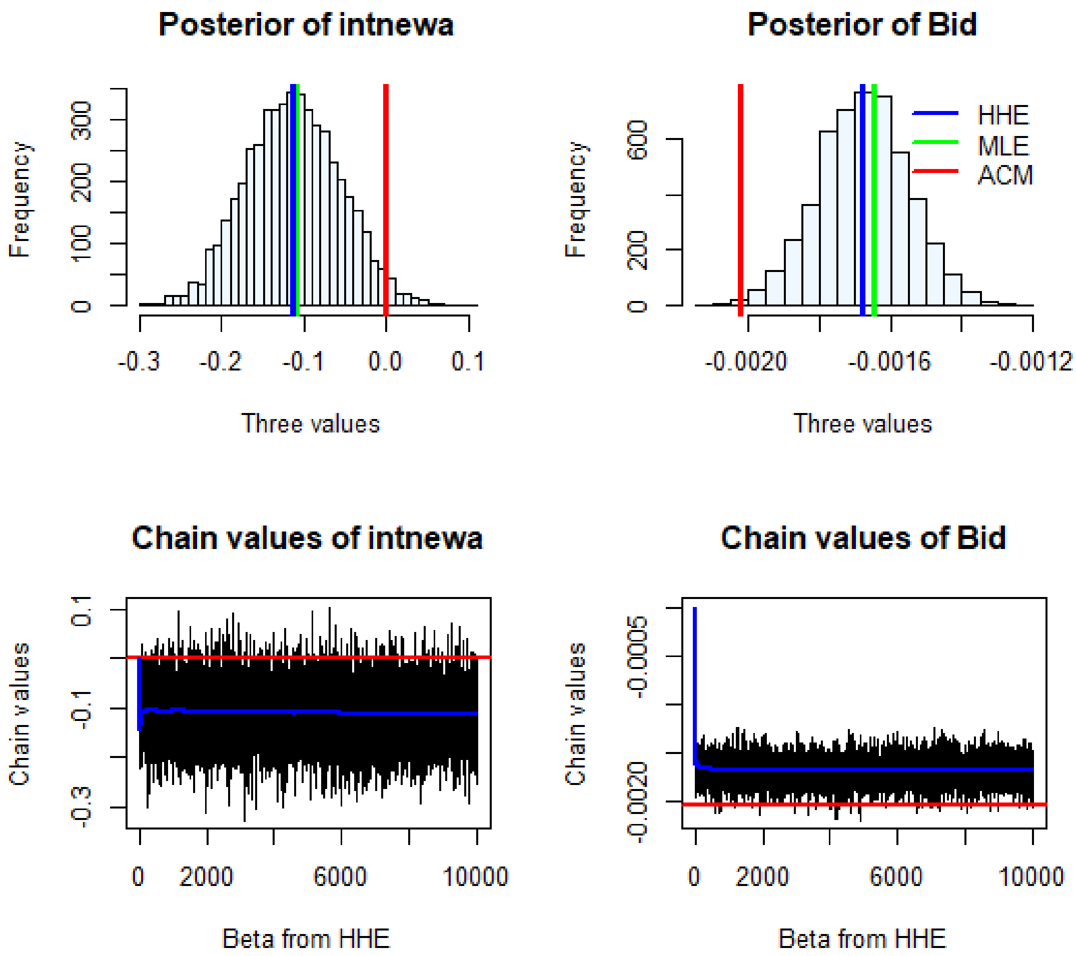


Figure 4.4: Parameters 11 and 12 from HHE

narrower distributions compared to ACM estimates, which makes HHE estimates distinguished from ACM estimates either from the distribution plots or chain value plots. Secondly, we can observe that the HHE estimates and MLE estimates are very close to each other and some of them overlap. The narrower HHE estimates distribution and the overlap between HHE and MLE estimates indicate that HHM reports more reliable MCMC simulation results. Thirdly, we notice that due to slow convergence, most ACM estimates are very close to zero, which is consistent with the conclusion that the variables in ACM are not significantly different from zero. With HHM, the variables converge to values different from zero. Overall, HHE is the choice over ACM for the MCMC simulation.

4.3 Follow-up Rounds Effects Using MCMC Method

4.3.1 Gibbs Sampling Process of Single Round

Probit models give estimates of α and δ instead of estimating β directly. Similarly to in Chapter three, we provide an alternative estimation framework, which can be used to estimate β. This Bayesian framework was proposed by (Araña and León, 2005), who followed earlier work by (McLeod and Bergland, 1999) and compared classical and Bayesian estimates with Monte Carlo simulations. Their results showed that the Bayesian approach performs better. Let WTP_{ij} represents the WTP of ith respond in the jth round. We start with the single-bounded model, assume that WTP follows a normal distribution, which is $WTP_{i1} \sim N\left(x_i'\beta, \sigma^2\right)$,

1. The prior distributions for β and σ are:

$$\beta/\sigma^2 \sim N(\beta_0, S_0)$$

$$\sigma^2 \sim \mathrm{IG}(a_1/2, b_1/2)$$

IG is the inverted gamma distribution, where $a_1/2$ and $b_1/2$ are the scale and shape parameters, respectively.

2. Set the initial value of β, σ and WTP, which can be obtained via classical MLE.

3. Sample the WTP from the posterior conditional density distribution,

$$f(WTP_{i1} \mid Y, \beta) = \begin{cases} \phi(WTP_{i1} \mid x_i'\beta, \sigma^2)\,\mathrm{T}[B_{i1}, \infty] & \text{if } y_{i1} = 1, \\ \phi(WTP_{i1} \mid x_i'\beta, \sigma^2)\,\mathrm{T}[0, B_{i1}] & \text{if } y_{i1} = 0, \end{cases}$$

where $\phi\mathrm{T}[a,b]$ is the density of a normal distribution truncated to the interval $[a,b]$. The inverse distribution approach described by Devroye (Devroye, 1986) can be used to produce a draw from a truncated normal distribution as follows:

$$WTP_{i1} = \begin{cases} x_i'\beta + \sigma\Phi^{-1}(U_{11}) & \text{if } y_{i1} = 1, \\ x_i'\beta + \sigma\Phi^{-1}(U_{12}) & \text{if } y_{i1} = 0, \end{cases}$$

where U_{11} is generated from a uniform density distribution in the interval $\left[\left(\Phi\left(\frac{B_{i1}-x_i'\beta}{\sigma}\right), 1\right)\right]$, and U_{21} from a uniform density distribution in the interval $\left[\Phi\left(\frac{-x_i'\beta}{\sigma}\right), \Phi\left(\frac{B_{i1}-x_i'\beta}{\sigma}\right)\right]$.

4. Sample β from the posterior distribution conditioned on σ and WTP,

$$\pi\left(\beta \mid Y, WTP_{i1}, \sigma^2\right) = \phi\left(\beta \mid \hat{\beta}_{WTP}, \tilde{S}\right)$$

$$\tilde{S} = \left(\tfrac{1}{\sigma^2}\textstyle\sum_{i=1}^{n} x_i x_i' + (S_0)^{-1}\right)^{-1}$$
$$\hat{\beta}_{WTP} = \tilde{V}\left(\tfrac{1}{\sigma^2}\textstyle\sum_{i=1}^{n} x_i WTP_{i1} + (S_0)^{-1}\beta_0\right)$$

5. Sample σ from the posterior distribution conditioned on β and WTP,

$$\pi\left(\sigma^2 \mid Y, WTP_{i1}, \beta\right) = f_{IG}\left(\sigma^2 \mid \frac{a_2}{2}, \frac{b_2}{2}\right)$$

$$b_2 = b_1 + \sum_{i=1}^{n}\left(WTP_{i1} - x_i'\beta\right)^2, \quad a_2 = a_1 + r, \text{ and } r = n.$$

6. Repeat until convergence is achieved.

4.3.2 Gibbs Sampling Process of Multiple Round

In this case, we estimate the parameters of interest using the information from the previous round. The first three steps of Gibbs sampling of multiple rounds are the same as the steps of Gibbs sampling of the single round.

4. Sample WTP_{i2} from the posterior conditional density distribution.

$$f\left(WTP_{i2} \mid Y_{ij}, \beta\right) = \begin{cases} \phi\left(WTP_{i2} \mid x_i'\beta, \sigma^2\right) \mathrm{T}\left[B_{i2,\infty}\right] & \text{if } y_{i1}y_{i2} = 1 \\ \phi\left(WTP_{i2} \mid x_i'\beta, \sigma^2\right) \mathrm{T}\left[B_{i1}, B_{i2}\right] & \text{if } y_{i1}\left(1 - y_{i2}\right) = 1 \\ \phi\left(WTP_{i2} \mid x_i'\beta, \sigma^2\right) \mathrm{T}\left[B_{i2}, B_{i1}\right] & \text{if } y_{i2}\left(1 - y_{i1}\right) = 1 \\ \phi\left(WTP_{i2} \mid x_i'\beta, \sigma^2\right) \mathrm{T}\left[0, B_{i2}\right] & \text{if } \left(1 - y_{i1}\right)\left(1 - y_{i2}\right) = 1 \end{cases}$$

$$WTP_{i2} = \begin{cases} x_i'\beta + \sigma\Phi^{-1}\left(U_{12}\right) & \text{if } y_{i1}y_{i2} = 1 \\ x_i'\beta + \sigma\Phi^{-1}\left(U_{22}\right) & \text{if } y_{i1}\left(1 - y_{i2}\right) = 1 \\ x_i'\beta + \sigma\Phi^{-1}\left(U_{32}\right) & \text{if } y_{i2}\left(1 - y_{i1}\right) = 1 \\ x_i'\beta + \sigma\Phi^{-1}\left(U_{42}\right) & \text{if } \left(1 - y_{i1}\right)\left(1 - y_{i2}\right) = 1 \end{cases}$$

where U_{12} is generated from a uniform density distribution in the interval

$$\left[\left(\Phi\left(\frac{B_{i2} - x_i'\beta}{\sigma}\right), 1\right)\right]$$

U_{22} is generated by a uniform density distribution in the interval

$$\left[\left(\Phi\left(\frac{B_{i1} - x_i'\beta}{\sigma}\right), \Phi\left(\frac{B_{i2} - x_i'\beta}{\sigma}\right)\right)\right]$$

U_{32} is generated by a uniform density distribution in the interval

$$\left[\left(\Phi\left(\frac{B_{i2} - x_i'\beta}{\sigma}\right), \Phi\left(\frac{B_{i1} - x_i'\beta}{\sigma}\right)\right)\right]$$

and U_{42} is generated by a uniform density distribution in the interval

$$\left[0, \left(\Phi\left(\frac{B_{i2} - x_i'\beta}{\sigma}\right)\right)\right]$$

5. Sample β from the posterior distribution conditioned on σ and WTP,

$$\pi\left(\beta \mid Y, WTP_{i2}, \sigma^2\right) = \phi\left(\beta \mid \hat{\beta}_{WTP}, \tilde{S}\right)$$

$$\tilde{S} = \left(\tfrac{1}{\sigma^2}\textstyle\sum_{i=1}^{n} x_i x_i' + (S_0)^{-1}\right)^{-1}$$
$$\hat{\beta}_{WTP} = \tilde{S}\left(\tfrac{1}{\sigma^2}\textstyle\sum_{i=1}^{n} x_i WTP_{i1} + (S_0)^{-1}\beta_0\right).$$

6. Sample σ from the posterior distribution conditioned on β and WTP,

$$\pi\left(\sigma^2 \mid Y, WTP_{i2}, \beta\right) = f_{IG}\left(\sigma^2 \mid \frac{a_2}{2}, \frac{b_2}{2}\right)$$

$$b_2 = b_1 + \sum_{i=1}^{n}\left(WTP_{i2} - x_i'\beta\right)^2, \quad a_2 = a_1 + r, \text{ and } r = \sum_{i=1}^{n} n.$$

7. Repeat until convergence is achieved.

4.3.3 Results and Discussion

Table 4.4 presents the MCMC simulation estimations of the single-bounded model. The MCMC simulation result of the double-bounded model is presented in Table 4.5 and that of the triple-bounded model in Table 4.6.

Parameter	Coef. Std. Err.		t	P> $\|t\|$
Intercept	-421.8672	15.1821	-27.7871	3.7766 e-158***
gtra	68.7248	4.7858	14.3603	7.4294 e-46***
geoegba	106.7952	4.5912	23.2608	9.9963 e-114 ***
inhospa	318.2607	12.0866	26.3318	3.2636 e-143 ***
expena	0.4456	0.1334	3.3403	8.4295 e-04 ***
watpa	13.9097	3.5730	3.8930	1.0030 e-04 ***
agea	-4.6164	1.4616	-3.1586	1.5949 e-03 ***
genda	13.3243	6.7015	1.9883	4.6837 e-02 **
mincomea	0.0344	0.0117	2.9360	3.3396 e-03 ***
ideologya	12.4692	5.0034	2.4921	1.2730 e-02 **
intnewa	-47.3907	5.0028	-9.4729	4.0886 e-21 ***
WTP: 810.8126				
***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level				

Table 4.4: Single-bounded MCMC Result

Parameter	Coef.	Std. Err.	t	P> $\|t\|$
Intercept	-419.8024	14.8988	-28.1770	2.9861 e-162 ***
gtra	67.7249	4.6338	14.6155	2.1008 e-47***
geoegba	99.3236	4.5568	21.7967	1.0689 e-100***
inhospa	316.2124	11.9894	26.3744	1.2166 e-143 ***
expena	0.0401	0.0211	1.9025	5.7157 e-02*
watpa	15.6014	3.3116	4.7111	2.5311 e-06***
agea	-2.4717	1.1234	-2.2002	2.7839 e-02 **
genda	12.0942	6.7641	1.7880	7.3838 e-02 *
mincomea	0.0189	0.0050	3.7778	1.6009 e-04 ***
ideologya	12.2364	4.778	2.5611	1.0463 e-02**
intnewa	-47.2553	4.9393	-9.5672	1.6773 e-21 ***
WTP: 566.0954				
***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level				

Table 4.5: Double-bounded MCMC Result

Parameter	Coef.	Std. Err.	t	P> $\|t\|$
Intercept	-638.9381	16.3035	-39.1902	3.4695 e-293***
gtra	96.0224	4.9765	19.2952	4.5170 e-80 ***
geoegba	120.8148	4.9067	24.6224	1.8960 e-126***
inhospa	187.1042	12.6908	14.7432	3.4522 e-48 ***
expena	0.1278	0.0340	3.7578	1.7335 e-04 ***
watpa	-1.0781	3.5956	-0.2998	7.6431 e-01
agea	-4.9355	1.2407	-3.9780	7.0465 e-05***
genda	-0.8273	7.3501	-0.1126	9.1039 e-01
mincomea	0.0223	0.0060	3.9168	9.0946 e-05***
ideologya	31.6792	5.2288	6.0586	1.4738 e-09 ***
intnewa	-40.4411	5.4298	-7.4480	1.1102 e-13 ***
WTP: 510.2154				
***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level				

Table 4.6: Triple-bounded MCMC Result

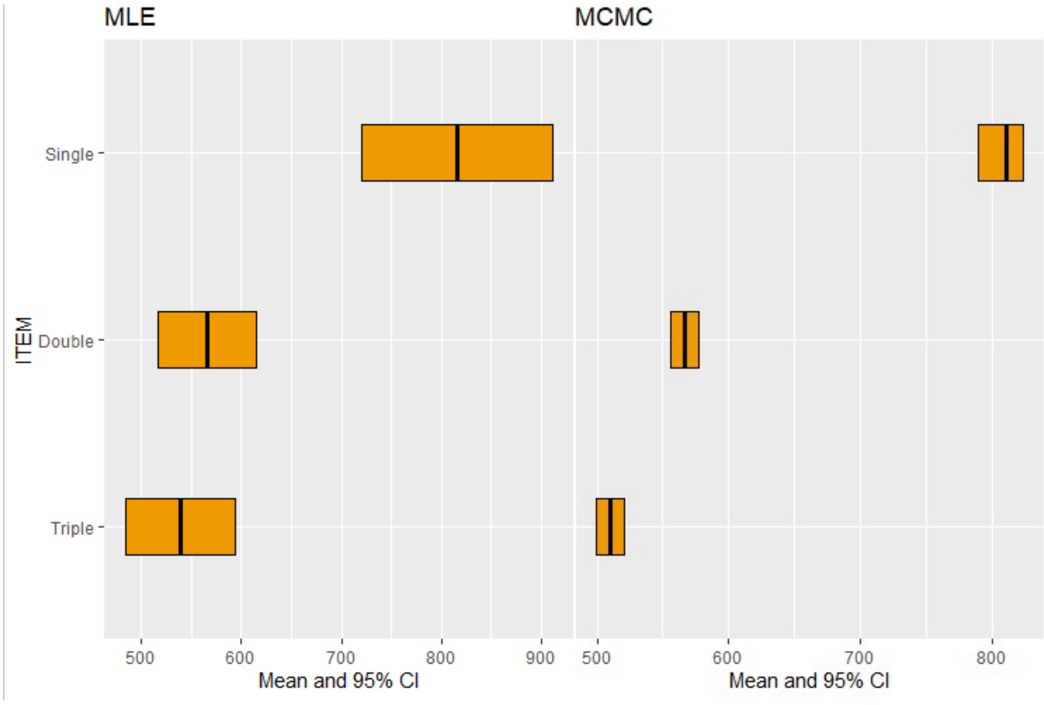


Figure 4.5: MLE and WTP Estimates

Simulated results are presented in Tables 4.4-4.6. All the explanatory variables in Table 4.4 show significance at least at the 0.05% level. In Table 4.5, variables “expena” and “genda” are significant at the 0.1% level, variable “agea” is significant at the 0.05% level, and all of the other variables are significant at the 0.01% level. Looking at Table 4.6, apart from the variable “genda” not being significant, all the explanatory variables are significant at the 0.01% level. From the single- to triple-bounded MCMC model, we can see that gender does not affect WTP significantly. The results from the three models reveal that MCMC methods produce highly consistent results with MLE methods, see Figure 4.5. The estimated mean WTP from the single-bounded MCMC model is 810.8126, close to the value from the MLE estimation of 816.56. The estimated mean WTP from the double-bounded MCMC model is 566.0954 which is also very close to the value obtained via MLE estimation of 565.79. The difference between triple-bounded MCMC and MLE models is also similar, being 510.2154 for MCMC estimation and 539.27 for MLE estimation. The double-bounded method has the closest estimation compared to MCMC and MLE methods. Furthermore, MCMC produces much narrower confidence intervals than MLE. In addition to the information in the table, we also obtained simulated values of σ^2 of the three MCMC models, which are 652.3805, 544.5231 and 540.8875 for single-, double- and triple-bounded models, respectively.

Chapter 5

Summary and Future Research

5.1 Chapter Summaries

Contingent valuation is a survey-based method to measure the benefits of non-market goods or services. Recent evidence has shown global climate variability and change have posed severe challenges that people have to face in developed and developing countries. This thesis carried out a contingent valuation study to evaluate people's WTP for the improvement of environmental quality in China using a face-to-face survey.

5.1.1 Chapter One

In chapter one, we first compared different survey modes of telephone, online, and face-to-face surveys. While the low cost of telephone and online surveys has made them a dominant method of data collection, this thesis implemented face-to-face mall-intercept interviews for the following reasons. Firstly, it served as the most effective means of producing high-quality data. Secondly, face-to-face interviews were more suitable for lengthy surveys in comparison to other survey modes, as the interviewers could encourage respondents to finish the survey. Moreover, respondents have opportunities to clarify any questions they might have with the help of interviewers.

We interviewed 1,044 participants, each answered 96 questions in the questionnaires, and only eleven missed more than 10 questions. This provides evidence that face-to-face interviews could achieve a high response rate and is consistent with the advice by the NOAA panel (Arrow et al., 1993). Then, we discussed the hypothetical scenario in the CVM questions, which was the "geoengineering" project. This project aimed to reduce pollution and provide people with access to a better living environment of clean air and water.

Understanding different types of values is very helpful to choose suitable methods for analysis. The final part of chapter one showed the derivation of WTP as a compensating variation. We classified the types of values and specified the stated preference method for non-use values. Then, we showed the conceptual framework for non-market valuation and used it to derive the compensating variation. The framework and the derivation of WTP could guide researchers in order to calculate WTP from theoretical perspectives.

5.1.2 Chapter Two

There were two topics in Chapter two. The first one was to describe the complete process of the survey design, including the establishment of the objective, survey mode and target population; determining the elicitation technique and format for CVM questions; the presentation of a testing survey and the training of interviewers. The objective was to elicit people's WTP for the improvement of environmental quality, so the "warming-up" questions were presented as easy questions which related to the topic. These initial questions led respondents to start the face-to-face interviews and encouraged overall participation. Our target population was the population of China, so we selected four respective cities from south to north in China to implement the research. The payment format for WTP in CVM questions is an increase in annual income tax or household bills. For the elicitation format, this thesis adopted the iterative dichotomous-choice format over other options (e.g., open-ended format and payment card format) because it can reduce bias and produce more effective outcomes. There are eight payment levels provided for interviewers to ask the first WTP question with a random bid, with the bid then adjusted based on the previous answer as the rounds proceeded. To ensure interviews went as well as expected, we carried out focus groups and pre-tests to evaluate the questionnaire's design, and trained interviewers before going to shopping malls to interrupt passers-by.

Another topic was data cleaning. We specified four types of error in our dataset and then fixed them with existing methods; we then gave a data statistical description table for all of the variables with the minimum value, maximum value, mean and standard deviation. At the end of Chapter two, we applied a step-wise method for variable selection.

This thesis also took into account of the problems of the application of CVM in China, for example, poor questionnaire design, lack of pre-investigation and small sample size pointed out by H. Duan, L. Yan-Li and L. Yan (Duan, Yan-Li, and Yan, 2014).

5.1.3 Chapter Three

Chapter three investigated the multiple rounds effect using a traditional maximum likelihood estimation method. We summarised yes/no distributions along levels in each round and concluded that the rate of yes answers was decreasing as the bid level increased. The number of respondents was dropping: in round four the number was about half of that in round one. The estimated mean WTP values from single-, double- and triple-bounded MLE models are CNY816.56, CNY565.79 and CNY539.27, respectively. The difference between single- and double-bounded WTP indicates using single-bounded models alone will lead to unreliable estimates.

Results from the single-, double- and triple bounded models suggest that: (1) those who thought that they could benefit from “geoengineering” project were more likely to pay more for improvement in environmental quality; (2) spending on pollution reduction products positively affected the WTP value. The mean value of spending on pollution reduction is CNY447.41, which could be an alternative indicator or WTP but with bias. Then, we compared the estimated mean

WTP values from the single-, double- and triple-bounded methods as well as their confidence intervals calculated using the delta method and the bootstrap method, respectively.

We concluded that: (1) the difference in mean WTP between the single- and double-bounded methods was larger than that between the double- and triple-bounded models; (2) the bootstrap method produced wider confidence intervals than the delta method.

It is also interesting to compare WTP estimates from other similar CVM studies for climate change. The Los Angeles residents were willing to pay US$164.4 each year for preventing climate change, about 0.3 % percentage of their annual income in 1999 (Berk Richard A, 1999). Australian respondents were willing to pay US$241 - 341 for emissions reduction policy, about 0.4% - 0.6% percentage of their average annual income in 2015 (Williams, 2015). The ratio of third-round WTP value (539 RMB) to annual average income is 0.6% in our study which is very similar to the previous findings in the percentage of WTP to income.

5.1.4 Chapter Four

Chapter four started with the introduction of the Markov chain Monte Carlo method and continued with the implementation of Gibbs sampling to get a Bayesian model for the single-, double- and triple-bounded models. Finally, it ended with an interpretation of the MCMC estimations.

In the Bayesian probit regression model, we applied both the Albert and

Chibs method and the Holmes and Held method. We observed that the latter method had higher efficiency and produced more accurate estimates, which was confirmed by convergence checking. This thesis recommends Holmes and Held method when using the MCMC technique for probit regression and suggests future research into converge checking before setting burn-in period times.

We applied the single-, double- and triple-bounded frameworks proposed by Arañaand León (Araña and León, 2005) to determine the effect across the following rounds when using the MCMC Gibbs simulation. The MCMC estimation results from the single- and double-bounded models revealed that the MCMC methods produced results consistent with MLE methods since the values of mean WTP were very close. MCMC approach computing consistent estimators to MLE approach is also verified by other researchers (Luengo David, 2020; Z. Li and Yu, 2011).

The MCMC method produced different estimates from the MLE method with an improvement in the significance of variables. After 10000 simulations, all the variables were significant in the single- and double-bounded MCMC models, with 10 out of 11 variables represented as significant in the triple-bounded model. We also observed narrower confidence intervals in MCMC estimates. The evidence of MCMC improving the variable significance and producing narrower confidence intervals need to be identified by future research.

5.2 Future Research

There are several other topics which can be conducted in future research. Firstly, it will be interesting to explore how people make choices and how certain they are when facing survey-type questions. The WTP question was designed based on the assumption that respondents make choices or judgements according to their preferences. Investigating what influences people's choices from the perspective of psychological theories is also interesting.

There are two subsequent questions that the respondents would need to consider. The first one is how to indicate their WTP in a Yes/No format after a randomly assigned bid amount; their answer is the information received by the interviewers. Then, the respondents further consider whether or how to adjust their answers after the interviewer's follow-up bid values, which are based upon their prior answers. The process would continue until the respondents change their answers in the subsequent rounds, but respondents are not informed about this.

During this process, the interviewers attempt to ask for more realistic bid amounts from the respondents, while respondents also proceed to answer Yes/No according to the interviewers changing bid amount. According to Friston's process theory (Friston, FitzGerald, et al., 2017), this is also the process that the respondents learn from to optimise their benefit. It is believed that all behaviour is driven by one's own beliefs.

In terms of optimal behaviour, the first thing to do would be to try to reduce uncertainty. In process theory, it is explained that there are two ways of optimising behaviour. The first way is to maximise the value of the next stage. This way is very classical, but it does not work for all situations. For example, it does not work if the next thing to do is searching a result of uncertainty. Therefore, it is advised that finding the optimal behaviour is to optimise the beliefs.

In mathematical terms, the function to optimise in terms of a sequence of actions is a function of beliefs. In process theory, the action of selection is called neuronal processing and can be explained by maximising Bayesian model evidence or minimising the variation of free energy. People must believe the actions they choose will minimise the expected free energy principle which was raised by Friston in 2006 (Friston, Kilner, and Harrison, 2006). We would like to continue research on this topic in the future.

Another example of possible future work is a direct continuation of existing research. Firstly, we would like to investigate the WTP from household bills to see whether it generates any different results (e.g. is there a significant difference between WTP from income tax).

Secondly, it would benefit future research to expand our model with additional variables involved. At present, after variable selection, we only used 10 variables within the model. In the future, we would like to add interaction terms to see whether they provide a better explanation of the models.

Finally, although the multiple dichotomous-choice methods have gained temporary approval as a means of obtaining precise information, the anchoring effect from the starting bid (Rozan, Laisney, et al., 2006; Chien, Huang, and Shaw, 2005) is worth exploring. We are interested in the method proposed by

Herriges and Shogren (Herriges and Shogren, 1996) to measure this starting point bias.

Appendix A

Three Articles

A.1 News One

Traffic Signal Funds Required

Developers Must Put up Surety Bond

by Jeffrey Cohen
Broomfield County Star June 15, 2011

A new Broomfield County policy will ensure that the next time a community needs a new traffic light to handle traffic associated with a commercial development, it will have the funds necessary to pay for it.

Developers who want to begin work on a new subdivision will be required to put up a surety bond, probably as much as $300,000, said Dorothy Doyle, the county's traffic division director. Traffic signals range in price from $60,000 for those strung on wires to $300,000 for a sturdier mast arm signal.

The impetus for the requirement comes from six recent cases in which traffic signals ended up being needed at communities where the developer had finished building, or in which the county had not initially heard concerns about a light, Doyle said.

The county will be able to hold the surety well after the subdivision is built, Doyle said, adding that the developer will be required to notify the county as it nears completion.

"We've always required developers to defray costs associated with the impact of their projects on local traffic, so this is nothing out of the ordinary," Doyle said.

Kevin Bain, President of GL Homes, Inc., the largest developer in the county, said many of his company's developments qualify for a signal anyway, adding that it's an appropriate issue for the county to address.

"It's a safety issue for our residents," Bain said. "We don't have an issue whatsoever with posting the surety."

Harry Halman, chairman of the Broomfield Chamber of Commerce, said the new surety policy makes sense.

"I think that the new requirements of anticipating the need for a traffic light are very valid, because inadequate traffic control is likely to discourage shopping downtown," said Halman.

（1）需要更严格的污染法规来应对气候变化

新的研究发现，提出的二氧化碳的减排目标将是无效的

专家们今天宣布，为了避免气候变暖带来的灾难性后果，工业化国家需要制定比联合国倡议更加严格的反污染限制。美国地球物理科学家学会，根据一项新研究得出这一结论：人类二氧化碳排放的环境影响可能比之前估计的要多得多。这项研究由麻省理工学院的研究人员完成，他们与美国地球物理科学家学会（AAGS）无关，他们在今年早些时候在“自然科学”杂志上发表了他们的研究结果。

美国地球物理科学家学会的发言人，来自哈佛大学的 Alan 博士说到：在这项研究之前，科学界认为二氧化碳的排放量足够被减缓并且其排放量可以被稳定到 450-600ppm。实现联合国在 2006 年提出的目标。但是这个研究小组在“自然科学”上发表的***数据和计算机模拟***表明，这种策略将完全无效。艾伦博士告诉新闻记者：即使我们以某种方式停止二氧化碳的排放，自然科学杂志的研究也表明，它还是能对地球的气候产生不可逆转的破坏性影响。美国地球物理科学家学会 AAGs 报告指出，自然科学研究“只支持一个结论：削减碳排放的力度必须比人们此前认为的要大得多.” 因此，“工业化社会有必要采取更为严厉的反污染控制措施”。

迄今为止，连英国和美国这样的国家都不愿意采取符合联合国标准的政策，因为担心这些措施会对企业和消费者造成负担，该报告承认，及时是更低的二氧化碳排放上限，也会产生更大的经济成本。“是的，我们都需要作出牺牲”。艾伦博士在 AAGs 报告的新闻发布会上说：“正是因为工业化国家的居民几十年来一直坚持要维持生活水平，我们才陷入了这种混乱”。他在华盛顿特区的记者大会上说。

中心思想：美国地球物理科学家学会，呼吁制定比联合国提出的二氧化碳排放控制目标更为严格的法规

A.2 News Two

Scientists: Even Stricter Anti-Pollution Regulations Needed to Fight Climate Change

New study finds proposed CO_2-emission targets will be ineffective

by Andrew Taylor
April 21, 2011

WASHINGTON, D.C. Staving off the catastrophic effects of global warming will require industrialized countries to enact anti-pollution limits even stricter than ones proposed by the United Nations, a group of expert scientists announced today.

The group, the American Academy of Geophysical Scientists, based this conclusion on a new study finding the environmental impact of human carbon dioxide (CO_2) emissions is likely to be significantly more severe than previously estimated.

The study was done by researchers from the Massachusetts Institute of Technology who were unaffiliated with AAGS and who published their findings earlier this year in the journal *Nature Science*.

"Before this study," said AAGS spokesman Dr. Alan M. Williams of Harvard University, "the scientific community assumed it would be enough to gradually slow down and then stabilize CO_2 emissions at 450-600 parts per million," a target approved by the United Nations in 2006. "But the data and computer simulations published by this research team in *Nature Science* show that this strategy will be completely ineffective," Dr. Williams said.

"Even if we somehow stopped emitting CO_2 into the atmosphere today," Dr. Williams told reporters, "the *Nature Science* study shows there would be irreversible and devastating effects to the earth's climate."

The AAGS report states that the *Nature Science* study "supports only one conclusion: cutbacks on carbon emissions will have to be much more drastic than anyone previously believed." As a result, "it will be necessary for industrialized societies to enact much more drastic anti-pollution controls," the AAGS report concludes.

"World governments have a wide range of pollution-cutting tools at their command — 'cap and trade,' fuel taxes, restrictions on the production and use of electricity, subsidies for solar power," said Dr. Williams. "It's time to use them," he said.

Industrialized nations such as the United States and Great Britain have so far balked at adopting policies deemed essential to meeting the U.N.'s 450-600 ppm target because of concerns over the burdens such measures would inflict on businesses and consumers. The even lower CO_2 ceiling by the AAGS — 175 ppm — would impose even larger costs, the report acknowledged.

"Yes, we will all need to make sacrifices," stated Williams in a press conference announcing the AAGS report. "It's precisely because the residents of industrialized countries have for decades insisted on a standard of living that exceeds the capacities of the natural environment that we are in this mess," Williams told an assembly of reporters in Washington, D.C.

CO_2 emissions and climate change. Recent study suggests that CO_2 emissions from power plants and other sources will cause "irreversible" damage to the environment even at levels proposed by the U.N. On this basis, AAGS has called for even stricter anti-pollution regulations. (Credit: AAGS Report, "Climate Change: The Urgent Need to Cut Back.")

（2）应对气候变化需要更多技术，而不是更多限制

新的研究发现提出的 CO_2 限制将无效

科学家们今天宣布，为了避免气候变暖带来的灾难性后果，工业化国家需要将重点从反污染法规转向旨在对抗气候变化影响的新技术。美国地球物理科学家学会，根据一项新研究得出这一结论：人类二氧化碳排放的环境影响可能比之前估计的要多得多。这项研究由麻省理工学院的研究人员完成，他们与美国地球物理科学家学会（AAGS）无关，他们在今年早些时候在"自然科学"杂志上发表了他们的研究结果。

美国地球物理科学家学会的发言人，来自哈佛大学的 Alan 博士说到：在这项研究之前，科学界认为二氧化碳的排放量足够被减缓并且其排放量可以被稳定到 450-600ppm。实现联合国在 2006 年提出的目标。但是这个研究小组在"自然科学"上发表的***数据和计算机模型***表明，这种策略将完全无效。艾伦博士告诉新闻记者：即使我们以某种方式停止二氧化碳的排放，自然科学杂志的研究也表明，它还是能对地球的气候产生不可逆转的破坏性影响。

美国地球物理科学家学会 AAGs 报告指出，自然科学研究"只支持一个结论:限制排放是一种浪费和徒劳的策略。"相反，报告鼓励取消对控制气候变冷技术研究的限制。(报告支持对控制气候变冷技术的研究)。"全球各地的绘图板上都有很多这样的技术。"艾伦博士说到，" 陆基过滤器可以去除空气中过量的二氧化碳，可以打开和关闭高空反射器以减少太阳能加热；有机物质可以添加到海洋中，以加速自然的二氧化碳吸收。"

美国地球物理科学家学会报告的结论是，开发这些所谓的"地球工程"**技术**，不仅比制定排放限制更加有效，而且还可以使消费者和企业免受沉重经济成本的压力，这些成本压力来自为将二氧化碳浓度降低到 450ppm 及以下的相关法规。人类在历史上一直面临着来自自然的挑战，我们从未屈服于这些挑战——我们总是以聪明才智战胜它们。想想今天的高产农业技术，现代医学的奇迹，以及城市工程的惊人壮举。现在是我们创新摆脱困境的时候了。

中心思想：应对气候变化，要加强对能对抗气候变化的新科技的研究，而不是严格控制二氧化碳排放。

A.3 News Three

Scientists: More Technology, Not More Limits, Needed to Fight Climate Change

New study finds proposed CO_2-emission limits will be ineffective

by Andrew Taylor
April 21, 2011

WASHINGTON, D.C. Staving off the catastrophic effects of global warming will require industrialized countries to shift emphasis from anti-pollution regulations to new technologies aimed at counteracting the effects of climate change, a group of expert scientists announced today.

The group, the American Academy of Geophysical Scientists, based this conclusion on a new study finding the environmental impact of human carbon dioxide (CO_2) emissions is likely to be significantly more severe than previously estimated.

The study was done by researchers from the Massachusetts Institute of Technology who were unaffiliated with AAGS and who published their findings earlier this year in the journal *Nature Science*.

"Before this study," said AAGS spokesman Dr. Alan M. Williams of Harvard University, "the scientific community assumed it would be enough to gradually slow down and then stabilize CO_2 emissions at 450-600 parts per million," a target approved by the United Nations in 2006. "But the data and computer models published by this research team in *Nature Science* show that this strategy will be completely ineffective," Dr. Williams said.

"Even if we somehow stopped emitting CO_2 into the atmosphere today," Dr. Williams told reporters, "the *Nature Science* study shows there would be irreversible and devastating effects to the earth's climate."

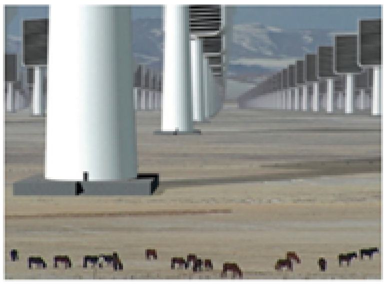
The AAGS report states that the *Nature Science* study "supports only one conclusion: limiting emissions is a wasteful and futile strategy." Instead the report urges removal of restrictions on research into technologies for controlled climate cooling.

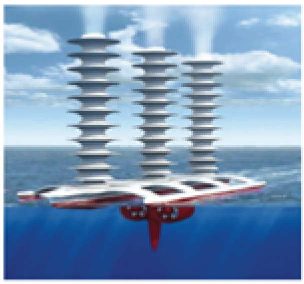
"There are scores of such technologies on drawing boards around the globe," said Dr. Alan Williams. "Land-based filters could remove excess CO_2 from the air; high-altitude reflectors could be turned on and off to reduce solar heating; organic materials could be added to the ocean to speed up natural CO_2 absorption."

Developing these so-called "geoengineering" technologies, the AAGS report concludes, would not only be more effective than enactment of emission restrictions, but also spare consumers and businesses from the heavy economic costs associated with the regulations necessary to reduce atmospheric CO_2 concentrations to 450 ppm or lower.

"Human beings have faced challenges from nature throughout history," Williams told reporters at a press conference. "We've never succumbed to those challenges – we've always overcome them with ingenuity."

"Consider today's high-yield agricultural techniques, the miracles of modern medicine, and the breathtaking feats of urban engineering," Williams stated. "Well, it's time for us to innovate our way out of another jam."





Geoengineering response to climate change. AAGS report proposes "geoengineering" after study finds that without "measures to remove gases already in the atmosphere or induce atmospheric cooling, existing CO_2 concentrations will cause irreversible environmental damage." Filters (left) could be placed in wilderness areas and that would soak up billions of tons of CO_2 from the atmosphere. Turbine-fitted vessels (right) could spray a mist to whiten clouds and make them more reflective of incoming sun light. (Credit: AAGS Report, "Beating Climate Change: Creating New Technologies, Not Restricting Old Ones.")

（3）交通信号基金刻不容缓

开发商必须提出担保债券

美国菲尔德县推出了一项新的政策，这项政策将确保下次社区如果需要新的交通信号灯来处理与商业开发相关的流量时，它将拥有能够支付它的必要的资金。该县交通部门负责人多萝西·多伊尔(Dorothy Doyle)说，想要开始开发一个新的细分市场的开发商，可能需要缴纳高达 30 万美元的保证金。交通信号的价格区间从 6000 美元到 30 万美元不等。

多伊尔说，这一要求的动力来自最近发生的六起案例，这些案例中，开发商已完成建设的社区，或该县最初没有听说过灯光问题的社区，最终需要使用交通信号。多伊尔说，在建设完这个小区后，该县将能够很好地承担担保责任。他还说，开发商需要在临近竣工时通知该县。他还说：我们一直要求开发商支付与他们的项目对当地交通的影响相关的费用，所以这并不是什么不同寻常的事情。

该郡最大的开发商 GL Homes Inc 的总裁凯文•贝恩(Kevin Bain)表示，无论如何，他的公司的许多开发项目都有资格发出这样的信号，他补充说，这个问题适合这个郡来解决。贝恩表示:“对我们的居民来说，这是一个安全问题”。布罗姆菲尔德商会(Broomfield Chamber of Commerce)会长哈里•哈曼(Harry Halman)表示，新的担保政策是有道理的。哈尔曼说:“我认为，人们对交通灯的需求有了新的要求，这是非常合理的，因为交通管制不力可能会阻碍人们在市中心购物。”

中心思想：美国一市政当局通过了一项条款，要求当地开发商提供“担保债券”（一种资金支持）来覆盖当地新的交通信号的安装。

Appendix B

Survey

Attitude towards environment and climate change

Firstly, we invite you to read a piece of news and an article from Natural Science. Now recall what you read and answer the following the questions.

Treatment (single)

- ○ Anti-pollution
- ○ Geoengineering
- ○ Control

Please indicate your level of agreement or disagreement with each statement

1、single choice questions.

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Requiring developers to post bonds to finance traffic signals is a good idea. (3th news)						
Nature Science study is convincing						
Scientists who did the study were biased.						
Computer models are not a reliable basis for predicting impact of CO2.						
More studies must be done before policymakers rely on findings						

Now we want to know your attitude towards climate change.

2、single choice questions

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Global warming brings serious environmental risks						
It is important to take actions to reduce global warming.						
Average global temperatures are increasing						
Human activity causing global temperatures to rise						
Unless action, there will be bad consequences for human beings						
It’s very dangerous living near the nuclear station.						

Next, we want to know if you are willing to pay a certain price for the great improvement of the living environment and make a certain contribution. Please ask the assistance of the interviewers.

3、The current environmental problems affecting people's quality of life in China are mainly air pollution, water pollution, and the community environment. Now China has set up a project to improve people's living environment -- “Earth Engineering” . The establishment of this project can greatly improve your living environment, comprehensively controlling air pollution sources, greatly controlling the quality of living water and increasing green space, which makes you to live in the environment that has no concern of pollution. If an increase amount on your income tax would be charged per year as your willing to pay for the exchange of the action of this project and corresponding environment. If _(random start number)___ will be increased on your income tax per year, are you willing?

- ☐ Willing
- ☐ Not willing
- ☐ 5
- ☐ 19
- ☐ 57
- ☐ 95
- ☐ 285
- ☐ 476
- ☐ 952
- ☐ 1904

4 , If the willing to pay is nothing to do with the income tax, it would be charged from the household water and electricity bill. If your bill will increase__(random start number)__per year, are you willing?

- ☐ Willing
- ☐ Not willing
- ☐ 5
- ☐ 18
- ☐ 54
- ☐ 90
- ☐ 271
- ☐ 453
- ☐ 906
- ☐ 1818

Please indicate your level of agreement or disagreement with each statement.

5、single choice questions

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
This geo-engineering project will benefit us						
This geo-engineering project will put us in risk						
Good idea for government to consider amount public willing to pay						

Residents from poor households can afford to pay less, so views will have less weight						
Government officials should rely on scientific expertise						
Right of individual should not depend on how much others are willing to pay to avoid damage						
Already pay too much in taxes to consider paying more						
Don't trust most members of public to have well informed views						

Then we want to your health situation

6、Do you have the following disease? (Multi-choice questions)

☐ asthma
☐ pulmonary disease
☐ Heavy metal poisoning
☐ Impaired hearing
☐ Environmental-related infectious diseases
☐ Other diseases related to the environment ____________
☐ None of the above

7、Have you seen a doctor in the past 6 months? If so, what is the reason?

○ yes ____________
○ no

8、Have you been hospitalized in the past 6 month? If so, what is the reason?

○ yes ____________
○ no

9、Do you take anti-aging drug or use related production ?

○ yes
○ no (to question 11)

10、How often do you take anti-aging drug or use related production?

○ everyday
○ 2-3 times a week
○ once a week
○ 2-3 a month
○ once a month

11、Do you have expenditure on dusk masks, air purifiers, water filters, etc. to deal with pollution? If so, what is your annual expenditure?

- ○ yes, the annual expenditure is-- ____________
- ○ no

Now we want to know your social attitude. A total of 7 levels can reflect your attitude.

12、Single-choice questions

	Strongly disagree	Disagree	Slightly disagree	Neither disagree nor agree	Slightly agree	Agree	Strongly agree
Need a fairness revolution							
Government puts too many restrictions on what businesses and individuals							
Best way to get ahead in life is to do what told to do							
Most important things in life happen by chance							
Society works best if power shared equally							
Even disadvantaged should have to make own way in world							
Society in trouble because people do not obey authority							
Course of lives largely determined by forces beyond our control							
Our responsibility to reduce differences in income between rich and Poor							
Better off when compete as individuals							
Society better off if people in charge imposed strict and swift							
Succeeding in life is a matter of chance							

We want to know your attitude towards government intervention and making decisions on your own.

13、Single choice questions

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Government interferes far toomuch in everyday lives						

Government needs to make lawsthat keep people from hurting themselves						
Not governments business to protect people from themselves						
Government should stop telling people how to live their lives						
Government should put limits on choices individuals can make						
Government should do more to advance societys goals, even if limiting Freedom						

People often have differences on issues of equality and discrimination. We want to know your attitude.

14、Single choice questions

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Gone too far in pushing equal rights in thiscountry						
Society better off ifdistribution of wealth more equal						
Need to reduce inequalitiesbetween rich/poor, Han/ethnic minorities						
Discrimination against minorities still a very serious						
Seems like blacks, women,homosexuals and other groups want special Rights						
Society has become too soft andfeminine						

How much do you think each of the following poses a risk to the safety and health of people in our society?

15、Score the following statement, 0 represents no risk at all, 10 represents Extreme risk.

	0	1	2	3	4	5	6	7	8	9	10
Private gun possession											
Global warming											
Air-pollution											
water pollution											
Nuclear power											
Legalization of marijuana											

Chemical additives in food											
	0	1	2	3	4	5	6	7	8	9	10
Domestic terrorism by Muslim extremists											
Increased immigration											
Lawsuits against reporters and news media for libel											
Nanotechnology											
Synthetic biology											
Indoor exposure to second-hand cigarette smoke											
Speech inciting racial hatred											
	0	1	2	3	4	5	6	7	8	9	10
Genetically modified foods											
Illegal drug trafficking											
Government regulation of businesses											
Teenage pregnancy											
Exposure to electromagnetic fields from powerlines											
Cuts in government support for higher education											
Childhood vaccinations											
	0	1	2	3	4	5	6	7	8	9	10
Military participation in war zones											
Government budget deficits											
he accumulation of spent nuclear fuel from nuclear power plants											
Climate change											

We would like to know your basic information as a respondent, we won’ t ask your name, phone number and address, please feel free to fill.

16、Age

____

17、Gender

- ○ Male
- ○ Female

18、Education

- ○ never
- ○ primary school
- ○ secondary school
- ○ high school
- ○ adult high shcool， night school
- ○ Adult college
- ○ undergraduate degree
- ○ postgraduate degree
- ○ PhD degree and above

19、The way to accept education

- ○ full-time
- ○ part-time
- ○ unknown

20、Employment status

- ○ Full-time
- ○ Part-time
- ○ Temporarily laid off
- ○ Unemployed
- ○ Retired
- ○ Permanently disabled
- ○ Homemaker
- ○ Student
- ○ Other ____________

21、Monthly income (RMB)

- ○ 2000 and below
- ○ 2001-3000
- ○ 3001-5000
- ○ 5001-8000
- ○ 8001-12000
- ○ 12001-20000
- ○ 20000 and above

22、Family income (RMB)

- ○ 0-20,000
- ○ 20,001-50,000
- ○ 50,001-80,000
- ○ 80,001-120,000
- ○ 200,001-300,000
- ○ 300,001-1000,000
- ○ 1000,001-10,000,000
- ○ 10,000,000 and above

23、Ethnic

- ○ Han
- ○ Zhuang
- ○ Hui
- ○ Man
- ○ Unihui
- ○ Other ____________

24、Marital status

- ○ Married
- ○ Seperated
- ○ Divorced
- ○ Widowed
- ○ Single
- ○ Other ____________

25、Political parties

- ○ Communist Party
- ○ Other parties
- ○ The masses

26、Importance of religion

- ○ Very important
- ○ Somewhat important
- ○ Not too importane
- ○ Not at all important

27、Religion

- ○ Buddhism
- ○ Taoism
- ○ Christian
- ○ Catholicism
- ○ Islam
- ○ Other
- ○ No religion
- ○ Unkhown

28、Ideology

- ○ Very liberal
- ○ Liberal
- ○ Moderate
- ○ Conservative
- ○ Very Conservative
- ○ Not sure

29、Interest in news and public affairs

- ○ Most of the time
- ○ Some of the time
- ○ Only now and then
- ○ Hardly at all
- ○ Do not know

30、Region

- ○ Northeast (Heilongjiang,Jilin,Liaoning)
- ○ East China (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Taiwan)
- ○ North China (Beijing, Tianjin, Shanxi, Hebei, Neimenggu)
- ○ Central China (Henan, Hubei, Hunan)
- ○ South China (Guangdong, Guangxi, Hainan, Xianggang, Aomen)
- ○ Southwest (Sichuan, Guizhou, Yunan, Chongqing, Xizang)
- ○ Northwest （Shanxi, Gansu, Qinghai, Ningxia, Xinjiang)

Appendix C

Interviewer Training

In the first section, we ensured that interviewers were made conscious of the question layout. There were ninety-six questions, starting with environmental news and ending with socio-demographic characteristics. A participant was to be asked to read one piece of news and a Nature Science article before answering the first section. Following this, the interviewer then carried out the WTP question section. There are eight initial bids, and the interviewer was told to randomly pick one of the eight bids and then initiate the WTP questioning. Interviewers were to adjust the follow-up bid according to participants' answers to the first bid—a larger bid when the answer was yes, while a lower bid when the answer was no.

The second training section was about interview skills. Firstly, qualified interviewers required good communication skills, especially when the interviews were all conducted in the public vicinity of the mall. Some sentences were pre-written as interjections to be worded for the interviewer's reference. Interviewers were free to change how to express questions but should ensure that the key points were all included. The first key point was a brief introduction to our research and ourselves to build trust, allowing for the participants to identify with the researchers. The second key point was regarding participants' privacy. Each participant was informed that their personal information was protected, allaying any potential concerns. Each questionnaire was recorded as a sample and did not include names or telephone numbers. The third key point was that we paid for their participation, and this was mentioned before they decided whether or not to answer the questionnaire, as each questionnaire contained ninety-six questions. It took between twenty to thirty minutes to answer the entire questionnaire. The interviewer also needed the ability to push participants to complete questions when they were not patient enough to stick through the entire questionnaire, as incomplete questionnaires were always considered invalid. Additionally, interviewers were expected to remain as objective as possible. We provided all interviewers with a standardised question format for each question. Interviewers were not allowed to ask questions in their own way, which is vital to avoid bias. The third skill was in relation to controlling the interview environment. Participants may be affected by nearby people due to inadvertently hearing or looking at someone else's answer, changing their judgement. Thus, interviewers were advised to interview people sitting alone or stagger the times in which there was more than one participant. When it comes to couples or groups of friends, we advised interviewers to ask only one of them. Moreover, interviewers should be aware of data balance. Balancing gender and age was very important for data quality. If they interview several young people, they next prioritise older individuals, with a similar method applied to men/women.

The third training section focused on problem-solving. During the interview process, we often encountered tricky questions and unusual situations. We put these together and shared them with the interviewers to address their encountered problems. For example, some questions were sensitive in the questionnaire, such as questions about social justice, racial discrimination and government regulation. Only a few of these had the neutral option of "neither agree nor disagree". Some people did not want to show their attitude on these issues, showing impatience and reluctance, asking: your research is about climate change and population, why are there so many questions about social justice and government? The interviewers were trained to understand the questionnaire set-up. We have a standard answer to this question.

> "This section is set to get an idea of two "worldviews" scale–Hierarchy-egalitarianism and Individualism-communitarianism. People with different 'worldviews' have different responses to climate change and environmental issues."

This answer was intended to help to alleviate their concerns. Generally, after we had explained the purpose of the survey, the participants seemed to be willing to answer this part seriously without further questions. Another typical question is that most people do not understand the jargon of "Nanotechnology", "Government budget deficits" etc. We prepared some explanatory materials to help develop their understanding during the interview.

Appendix D

Data Codebook

1. **treat** Treatment

Code	Label	Cleaned code	**Count**
1	Anti-pollution	1	350
2	Geoengineering	2	359
3	Control	3	328

2. **covin** Nature Science study is convincing

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	15
2	Moderately disagree	2	53
3	Slightly disagree	3	157
4	Slightly agree	4	370
5	Moderately agree	5	310
6	Strong agree	6	117

3. **biased** Scientists who did the study were biased.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	64
2	Moderately disagree	2	163
3	Slightly disagree	3	391
4	Slightly agree	4	228
5	Moderately agree	5	126
6	Strong agree	6	46

4. **campu** Computer models are not a reliable basis for predicting impact of CO_2.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	42
2	Moderately disagree	2	124
3	Slightly disagree	3	122
4	Slightly agree	4	270
5	Moderately agree	5	233
6	Strong agree	6	147

5. **morst** More studies must be done before policymakers rely on findings.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	12
2	Moderately disagree	2	18
3	Slightly disagree	3	56
4	Slightly agree	4	143
5	Moderately agree	5	293
6	Strong agree	6	502

6. **gwrisk** Global warming brings serious environmental risks.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	9
2	Moderately disagree	2	19
3	Slightly disagree	3	55
4	Slightly agree	4	122
5	Moderately agree	5	342
6	Strong agree	6	489

7. **acredgw** It is important to take actions to reduce global warming.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	5
2	Moderately disagree	2	10
3	Slightly disagree	3	42
4	Slightly agree	4	124
5	Moderately agree	5	278
6	Strong agree	6	577

8. **gtr** Average global temperatures are increasing.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	3
2	Moderately disagree	2	10
3	Slightly disagree	3	52
4	Slightly agree	4	135
5	Moderately agree	5	351
6	Strong agree	6	485

9. **hcgtr** Human activity causing global temperatures to rise

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	14
2	Moderately disagree	2	38
3	Slightly disagree	3	102
4	Slightly agree	4	237
5	Moderately agree	5	337
6	Strong agree	6	308

10. **uabad** Unless action, there will be bad consequences for human beings.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	4
2	Moderately disagree	2	10
3	Slightly disagree	3	50
4	Slightly agree	4	134
5	Moderately agree	5	286
6	Strong agree	6	552

11. **dlnuc** It's very dangerous living near the nuclear station.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	11
2	Moderately disagree	2	44
3	Slightly disagree	3	84
4	Slightly agree	4	179
5	Moderately agree	5	263
6	Strong agree	6	453

12. **yorn 1** Are you willing to pay for bid1?

Code	Label	Cleaned code	**Count**
1	yes	1	791
2	no	0	240

13. **bid1** The started bid given on income tax.

Code	Label	Cleaned code	**Count**
0	No response	0	1
1	5	5	225
2	19	19	202
3	57	57	160
4	95	95	119
5	285	285	106
6	476	476	100
7	952	952	80
8	1904	1904	44

14. **finalno1** The smallest no response number given on income tax.

Code	Label	Cleaned code	**Count**
0	No response	0	1
1	No at 5	5	116
2	No at 19	19	33
3	No at 57	57	93
4	No at 95	95	148
5	No at 285	285	177
6	No at 476	476	168
7	No at 952	952	131
8	No at 1904	1904	108
9	Yes at 1904	2000	62
mean	583.3098		

15. **yorn 2** Are you willing to pay for bid2?

Code	Label	Cleaned code	**Count**
1	yes	1	732
2	no	0	299

16. **bid2** The started bid given on household bills.

Code	Label	Cleaned code	**Count**
0	No response	0	1
1	5	5	189
2	18	18	191
3	54	54	180
4	90	90	135
5	271	271	95
6	453	453	99
7	906	906	91
8	1818	1817	56

17. **finalno2** The smallest no response number given on household bills.

Code	Label	Cleaned code	**Count**
0	No response	0	5
1	No at 5	5	148
2	No at 18	18	39
3	No at 54	54	72
4	No at 90	90	144
5	No at 271	271	189
6	No at 453	453	182
7	No at 906	906	106
8	No at 1818	1818	105
9	Yes at 1818	2000	45
mean	509.7870		

18. **geoegb** This geo-engineering project will benefit us.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	7
2	Moderately disagree	2	22
3	Slightly disagree	3	81
4	Slightly agree	4	311
5	Moderately agree	5	367
6	Strong agree	6	245

19. **geoegr** This geo-engineering project will put us in risk.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	20
2	Moderately disagree	2	84
3	Slightly disagree	3	199
4	Slightly agree	4	368
5	Moderately agree	5	249
6	Strong agree	6	112

20. **gidwtp** Good idea for government to consider amount public willing to pay.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	10
2	Moderately disagree	2	40
3	Slightly disagree	3	90
4	Slightly agree	4	262
5	Moderately agree	5	291
6	Strong agree	6	338

21. **poorlw** Residents from poor households can afford to pay less, so views will have less weight.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	141
2	Moderately disagree	2	154
3	Slightly disagree	3	189
4	Slightly agree	4	210
5	Moderately agree	5	176
6	Strong agree	6	161

22. **grlysci** Government officials should rely on scientific expertise.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	5
2	Moderately disagree	2	16
3	Slightly disagree	3	63
4	Slightly agree	4	139
5	Moderately agree	5	306
6	Strong agree	6	504

23. **idright** Right of individual should not depend on how much others are willing to pay to avoid damage.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	30
2	Moderately disagree	2	55
3	Slightly disagree	3	169
4	Slightly agree	4	241
5	Moderately agree	5	265
6	Strong agree	6	272

24. **paymore** Already pay too much in taxes to consider paying more.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	25
2	Moderately disagree	2	44
3	Slightly disagree	3	154
4	Slightly agree	4	304
5	Moderately agree	5	321
6	Strong agree	6	182

25. **ntpub** Don't trust most members of public to have well informed views.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	67
2	Moderately disagree	2	167
3	Slightly disagree	3	230
4	Slightly agree	4	266
5	Moderately agree	5	181
6	Strong agree	6	123

26. **disease** Do you have the following disease?

Code	Label	Cleaned code	**Count**
1	Asthma	1	
2	Pulmonary disease	1	
3	Heavy metal poisoning	1	
4	Impaired hearing	1	
5	Environmental-related infectious diseases	1	
6	Other diseases related to the environment	1	186
7	None of the above	0	851

27. **seendoc** Have you seen a doctor in the past 6 months? If so, what is the reason?

Code	Label	Cleaned code	**Count**
1	Yes	1	254
2	No	0	783

28. **inhosp** Have you been hospitalized in the past 6 month? If so, what is the reason?

Code	Label	Cleaned code	**Count**
1	Yes	1	28
2	No	0	1009

29. **antiage** Do you take anti-aging drug or use related production?

Code	Label	Cleaned code	**Count**
1	Yes	1	90
2	No	2	947

30. **tantiage** How often do you take anti-aging drug or use related production?

Code	Label	Cleaned code	**Count**
1	everyday	30	18
2	2-3 times a week	10	27
3	once a week	4	16
4	2-3 a month	2	17
5	once a month	1	17
6	Skip	6	896

31. **ifexpen** Do you have expenditure on dusk masks, air purifiers, water filters, etc. to deal with pollution?

Code	Label	Cleaned code	**Count**
1	Yes	1	617
2	No	0	420

32. **expen** If so, what is your annual expenditure?

Label	**Count**
mean	445.85286

33. **fair** Need a fairness revolution.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	9
2	Disagree	2	12
3	Slightly disagree	3	60
4	Neither disagree nor agree	4	224
5	Slightly agree	5	193
6	Agree	6	324
7	Strong agree	7	204

34. **gres** Government puts too many restrictions on what businesses and individuals.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	13
2	Disagree	2	52
3	Slightly disagree	3	173
4	Neither disagree nor agree	4	225
5	Slightly agree	5	250
6	Agree	6	209
7	Strong agree	7	107

35. **tell** Best way to get ahead in life is to do what told to do.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	140
2	Disagree	2	228
3	Slightly disagree	3	197
4	Neither disagree nor agree	4	197
5	Slightly agree	5	118
6	Agree	6	111
7	Strong agree	7	40

36. **chance** Most important things in life happen by chance.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	36
2	Disagree	2	92
3	Slightly disagree	3	130
4	Neither disagree nor agree	4	181
5	Slightly agree	5	280
6	Agree	6	237
7	Strong agree	7	75

37. **pequ** Society works best if power shared equally.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	52
2	Disagree	2	135
3	Slightly disagree	3	175
4	Neither disagree nor agree	4	284
5	Slightly agree	5	175
6	Agree	6	146
7	Strong agree	7	68

38. **disad** Even disadvantaged should have to make own way in world.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	11
2	Disagree	2	33
3	Slightly disagree	3	65
4	Neither disagree nor agree	4	161
5	Slightly agree	5	253
6	Agree	6	367
7	Strong agree	7	141

39. **nobey** Society in trouble because people do not obey authority.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	107
2	Disagree	2	107
3	Slightly disagree	3	205
4	Neither disagree nor agree	4	272
5	Slightly agree	5	115
6	Agree	6	92
7	Strong agree	7	27

40. **outc** Course of lives largely determined by forces beyond our control.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	46
2	Disagree	2	116
3	Slightly disagree	3	175
4	Neither disagree nor agree	4	199
5	Slightly agree	5	226
6	Agree	6	177
7	Strong agree	7	94

41. **ranp** Our responsibility to reduce differences in income between rich and Poor.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	12
2	Disagree	2	30
3	Slightly disagree	3	99
4	Neither disagree nor agree	4	259
5	Slightly agree	5	225
6	Agree	6	269
7	Strong agree	7	142

42. **compe** Better off when compete as individuals.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	42
2	Disagree	2	124
3	Slightly disagree	3	122
4	Neither disagree nor agree	4	270
5	Slightly agree	5	233
6	Agree	6	147
7	Strong agree	7	90

43. **strict** Society better off if people in charge imposed strict and swift.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	47
2	Disagree	2	58
3	Slightly disagree	3	128
4	Neither disagree nor agree	4	229
5	Slightly agree	5	243
6	Agree	6	211
7	Strong agree	7	118

44. **succd** Succeeding in life is a matter of chance.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	138
2	Disagree	2	258
3	Slightly disagree	3	169
4	Neither disagree nor agree	4	202
5	Slightly agree	5	134
6	Agree	6	74
7	Strong agree	7	61

45. **gintf** Government interferes far too much in everyday lives.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	29
2	Moderately disagree	2	84
3	Slightly disagree	3	292
4	Slightly agree	4	362
5	Moderately agree	5	151
6	Strong agree	6	86
8	No response		

46. **law** Government needs to make laws that keep people from hurting themselves.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	51
2	Moderately disagree	2	72
3	Slightly disagree	3	161
4	Slightly agree	4	350
5	Moderately agree	5	257
6	Strong agree	6	121

47. **protc** Not governments business to protect people from themselves.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	231
2	Moderately disagree	2	259
3	Slightly disagree	3	226
4	Slightly agree	4	153
5	Moderately agree	5	76
6	Strong agree	6	56

48. **stop** Government should stop telling people how to live their lives.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	94
2	Moderately disagree	2	135
3	Slightly disagree	3	252
4	Slightly agree	4	301
5	Moderately agree	5	144
6	Strong agree	6	79

49. **limit** Government should put limits on choices individuals can make.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	235
2	Moderately disagree	2	219
3	Slightly disagree	3	285
4	Slightly agree	4	148
5	Moderately agree	5	77
6	Strong agree	6	50

50. **goal** Government should do more to advance society's goals, even if limiting Freedom.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	190
2	Moderately disagree	2	208
3	Slightly disagree	3	247
4	Slightly agree	4	171
5	Moderately agree	5	96
6	Strong agree	6	87

51. **equr** Gone too far in pushing equal rights in this country.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	122
2	Moderately disagree	2	269
3	Slightly disagree	3	325
4	Slightly agree	4	174
5	Moderately agree	5	72
6	Strong agree	6	43

52. **wtheq** Society better off if distribution of wealth more equal.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	67
2	Moderately disagree	2	149
3	Slightly disagree	3	176
4	Slightly agree	4	276
5	Moderately agree	5	206
6	Strong agree	6	141

53. **reddif** Need to reduce inequalitiesbetween rich/poor, Han/ethnic minorities.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	25
2	Moderately disagree	2	75
3	Slightly disagree	3	177
4	Slightly agree	4	302
5	Moderately agree	5	262
6	Strong agree	6	170

54. **serious** Discrimination against minorities still a very serious.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	142
2	Moderately disagree	2	191
3	Slightly disagree	3	283
4	Slightly agree	4	209
5	Moderately agree	5	116
6	Strong agree	6	70

55. **sperit** Seems like blacks, women,homosexuals and other groups want special Rights

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	63
2	Moderately disagree	2	98
3	Slightly disagree	3	273
4	Slightly agree	4	327
5	Moderately agree	5	182
6	Strong agree	6	75

56. **soft** Society has become too soft and feminine.

Code	Label	Cleaned code	**Count**
1	Strongly disagree	1	101
2	Moderately disagree	2	164
3	Slightly disagree	3	298
4	Slightly agree	4	229
5	Moderately agree	5	132
6	Strong agree	6	84

Score the following statement, 0 represents no risk at all, 10 represents Extreme risk.

57. **gun** Private gun possession.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	6	7	9	8	30	16	84	132	131	603	11	8.85

58. **gw** Global warming.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	10	10	18	15	62	106	121	174	154	355	9	8.17

59. **airp** Air-pollution.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	3	2	1	11	39	88	112	191	161	427	1	8.53

60. **watp** water pollution.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	2	1	3	10	39	78	84	174	186	457	2	8.65

61. **nucp** Nuclear power.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	11	14	33	41	102	105	105	112	135	361	16	7.60

62. **legma** Legalization of marijuana.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	8	7	19	19	51	38	77	122	149	526	17	8.48

63. **chef** Chemical additives in food.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	9	18	30	54	123	102	135	160	102	298	6	7.42

64. **domes** Domestic terrorism by Muslim extremists.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	4	10	5	7	24	33	66	79	133	671	3	9.08

65. **immg** Increased immigration.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	51	61	94	66	155	116	131	134	82	95	47	5.62

66. **rept** Lawsuits against reporters and news media for libel.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	41	55	59	81	115	117	121	151	122	139	30	6.27

67. **natech** Nanotechnology possession.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	138	122	99	60	164	57	59	53	32	40	205	3.46

68. **sybio** Synthetic biology.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	107	117	103	80	161	93	85	63	50	61	111	4.31

69. **inexp** Indoor exposure to second-hand cigarette smoke.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	24	24	78	94	124	89	114	137	111	232	9	6.80

70. **speech** Speech inciting racial hatred.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	6	13	34	49	76	91	101	118	119	422	5	7.96

71. **genef** Genetically modified foods.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	29	52	69	96	166	113	95	122	65	202	28	6.15

72. **drug** Illegal drug trafficking.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	3	4	11	11	23	38	62	83	134	660	7	9.04

73. **greg** Government regulation of businesses.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	1	178	94	63	4	120	90	101	157	78		6.63

74. **teenp** Teenage pregnancy.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	79	55	52	94	157	75	84	117	121	147	53	5.84

75. **epele** Exposure to electromagnetic fields from powerlines.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	76	58	63	88	143	87	93	97	88	186	47	5.87

76. **gedu** Cuts in government support for higher education

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	16	24	27	48	90	81	109	148	135	337	16	7.62

77. **chva** Childhood vaccinations.

Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**mean**
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	62	89	47	40	117	65	81	100	100	225	108	5.82

78. **pwar** Military participation in war zones.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	10	18	36	31	109	81	115	181	132	299	21	7.51

79. **budget** Government budget deficits.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	17	38	66	57	119	105	118	142	132	210	31	6.72

80. **fuel** The accumulation of spent nuclear fuel from nuclear power plants.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	5	9	16	28	42	65	110	164	151	442	4	8.34

81. **clich** Climate change.

Code	1	2	3	4	5	6	7	8	9	10	0	mean
Risk	1	2	3	4	5	6	7	8	9	10	No response	
Count	11	15	16	25	88	99	153	178	180	254	15	7.62

82. **age** Age

Label	**Age**
mean	32.89

83. **gend** Gender.

Code	Label	Cleaned code	**Count**
1	Male	0	497
2	Female	1	536

male=0, female=1

84. **edu** Education.

Code	Label	Cleaned code	**Count**
1	Never	0	4
2	primary school	6	7
3	secondary school	9	39
4	high school	10	43
5	adult high	12	79
6	Adult college	13	167
7	undergraduate	16	554
8	postgraduate	20	128
9	PhD degree	22	16

85. **eduw** The way to accept education.

Code	Label	Cleaned code	**Count**
1	Full time	1	928
2	Part time	0	109

86. **emply** Employ status.

Code	Label	Cleaned code	**Count**
1	Full-time	1	777
2	Part-time	0	
3	Temporarily laid off	0	
4	Unemployed	0	
5	Retired	0	
6	Permanently disabled	0	
7	Homemaker	0	
8	Student	0	
9	Other	0	260

87. **mincome** Monthly income.

Code	Label	Cleaned code	**Count**
1	2000 and below	1500	80
2	2001-3000	2500	99
3	3001-5000	4000	272
4	5001-8000	6500	302
5	8001-12000	10000	169
6	12001-20000	15000	65
7	20000 and above	20000	35
mean	6535.44		

88. **fincome** Family income.

Code	Label	Cleaned code	**Count**
1	0-20,000	10000	39
2	20,001-50,000	35000	91
3	50,001-80,000	75000	188
4	80,001-120,000	100000	320
5	200,001-300,000	250000	259
6	300,001-1000,000	600000	98
7	1000,001-10,000,000	1000000	28
8	10,000,000 and above		8
mean	950789.06		

89. **ethnic** Ethnic.

Code	Label	Cleaned code	**Count**
1	Han	1	976
2	Zhuang	0	
3	Hui	0	
4	Man	0	
5	Unihui	0	
6	Other	0	61

90. **marital** Marital status.

Code	Label	Cleaned code	**Count**
1	Married	1	597
2	Seperated	0	
3	Divorced	0	
4	Widowed	0	
5	Single	0	
6	Other	0	439

91. **political** Political parties.

Code	Label	Cleaned code	**Count**
1	Communist Party	1	
2	Other parties	1	265
3	The masses	0	771

92. **imrelig** Importance of religion.

Code	Label	Cleaned code	**Count**
1	Very important	4	132
2	Somewhat important	3	360
3	Not too important	2	426
4	Not at all important	1	112

93. **ideology** Ideology.

Code	Label	Cleaned code	**Count**
1	Very liberal	5	254
2	Liberal	4	478
3	Moderate	3	193
4	Conservative	2	70
5	Very Conservative	1	8

94. **intnew** Interest in news and public affairs.

Code	Label	Cleaned code	**Count**
1	Most of the time	4	98
2	Some of the time	3	67
3	Only now and then	2	516
4	Hardly at all	1	339

95. **region** Region .

[htp]

Code		**Zhengzhou 1**	**Harbin 2**	**Changsha 3**	**Zhuhai 4**	**Total**
1	Northeast	12	239	5	6	262
2	East China	15	7	22	8	52
3	North China	17	2	5	8	32
4	Central China	179	1	212	25	
5	South China	23	0	14	189	417
6	Southwest	9	2	11	7	226
7	Northwest	4	4	6	5	29
	Total	259	255	276	253	1043

Appendix E

Stepwise Outcome of Variable Selection

Name	Description	min	max	mean	S. E.
covina	Agreement on "Nature Science study is convincing", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.231	0.0122
biaseda	Agreement on "Scientists who did the study were biased", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.321	0.0116
morsta	Agreement on "More studies must be done before policymakers rely on findings", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.412	0.0129

gtra	Agreement on "Average global temperatures are increasing.", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	5.197	0.0144
bid1a	The first random bid given to participants.	5	1904	314.5	0.0000
yorn2a	Dummy variable, the answer of willingness to pay question on household bill: 1,yes; 0, no.	0	1	0.761	0.0277
geoegba	Agreement on "This geo-engineering project will benefit us", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.045	0.0131
idrighta	Agreement on "Right of individual should not depend on how much others are willing to pay to avoid damage", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.426	0.0094
ntpuba	Agreement on "Don't trust most members of the public to have well informed views", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.673	0.0091
inhospa	Dummy variable, whether participants have seen a hospitalized in the past 6 month: 1, yes; 0, no.	0	1	0.027	0.0743

tantiagea	Continuous answer on how often participants take anti-aging drug or use related production, ranging from 0 (0 day per months) to 30 (everyday in a month).	0	30	6.348	0.0036
pequa	Agreement on "Society works best if power shared equally" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.068	0.0088
disada	Agreement on "Even disadvantaged should have to make own way in world" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	5.209	0.0100
nobeya	Agreement on "Society in trouble because people do not obey authority" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	3.454	0.0092
ranpa	Agreement on "Our responsibility to reduce differences in income between rich and Poor" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	4.959	0.0099
succda	Agreement on "Succeeding in life is a matter of chance" , 1-7 scale: 1, strongly disagree; 7, strongly agree.	1	7	3.388	0.0088

goala	Agreement on "Government should do more to advance society's goals, even if limiting Freedom", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.036	0.0089
equra	Agreement on "Gone too far in pushing equal rights in this country", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	2.934	0.0113
wtheqa	Agreement on "Society better off if distribution of wealth more equal", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.816	0.0102
reddifa	Agreement on "Need to reduce inequalitiesbetween rich/poor, Han/ethnic minorities", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	4.198	0.0108
seriousa	Agreement on "Discrimination against minorities still a very serious", 1-6 scale: 1, strongly disagree; 6, strongly agree.	1	6	3.174	0.0096
gwa	Perception of risk from global warming, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.141	0.0027
airpa	Perception of risk from air-pollution, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.502	0.0133
watpa	Perception of risk from water pollution, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.629	0.0140

legmaa	Perception of risk from legalization of marijuana, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	8.474	0.0059
natecha	Perception of risk from nanotechnology possession, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	3.504	0.0061
sybioa	Perception of risk from synthetic biology, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	4.357	0.0060
druga	Perception of risk from illegal drug trafficking, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	9.011	0.0076
budgeta	Perception of risk from government budget deficits, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	6.757	0.0053
clicha	Perception of risk from Climate change, 0-10 scale: 0, no risk at all; 10, extreme.	0	10	7.619	0.0064
mincomea	Monthly income.	1000	20000	6548	0.0000
intnewa	Participants' interest in news and public affairs, 1-4 scale: 1,hardly be interested; 4, most interested.	1	4	1.925	0.0143

Table E.1: Descriptive Statistics–Stepwise

Appendix F

Characteristics of Participants' Changing Mind

Figure 2.1 shows the changing time of the round t, that is the number of rounds between the start round to the finish round. Figure F.1 shows the frequency of changing time of participants. We can see 258 participants spent 1 changing time to switch their answer to the WTP question, counting the changing time 1-8. 241 participants spent 2 changing times and 201 participants spent 3 times switching their answers. The number of changing times is decreasing with the number going up. The participants with changing time from 1 to 3 take 70% of the samples. Table F.1 summaries the characteristics that have an effect on the changing time. We make the changing time the dependent variable and run a generalised linear regression with all the other independent variables in our database. In total, 21 variables show significance, most of them show negative signs, indicating that they

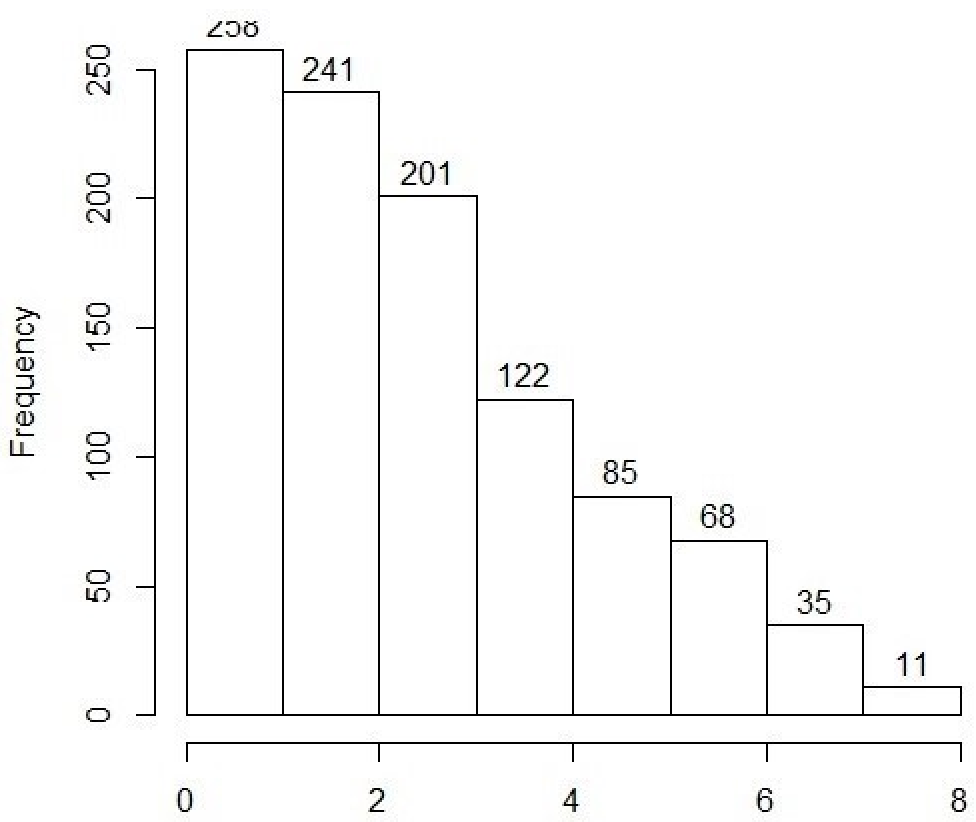


Figure F.1: Frequency of Changing Time

Parameter	Coef.	Std. Err.	t	P> $\|t\|$
(Intercept)	6.182e+00	8.412e-01	7.349	6.02e-13 ***
covina	-1.026e-01	6.231e-02	-1.646	0.100212
yorn1a	-7.808e-01	2.280e-01	-3.424	0.000656 ***
bid1a	-5.391e-04	1.959e-04	-2.752	0.006087 ***
finalno1a	5.736e-04	1.538e-04	3.729	0.000209 ***
yorn2a	-4.754e-01	2.092e-01	-2.273	0.023363 **
bid2a	-4.810e-04	1.775e-04	-2.710	0.006909 ***
finalno2a	5.194e-04	1.645e-04	3.158	0.001662 ***
poorlwa	-1.184e-01	4.295e-02	-2.757	0.006003 ***
ntpuba	-1.007e-01	4.874e-02	-2.066	0.039267 **
diseasea	-4.227e-01	1.767e-01	-2.392	0.017050 **
inhospa	-5.936e-01	3.903e-01	-1.521	0.128785
ifexpena	2.667e-01	1.432e-01	1.863	0.062983 *
expena	-1.204e-04	5.419e-05	-2.222	0.026622 **
tella	1.153e-01	4.243e-02	2.718	0.006751 ***
ranpa	-1.330e-01	5.092e-02	-2.613	0.009195 ***
protca	-8.527e-02	5.274e-02	-1.617	0.106363
equra	9.642e-02	6.214e-02	1.552	0.121215
guna	-6.713e-02	3.852e-02	-1.743	0.081820 *
nucpa	6.994e-02	2.831e-02	2.471	0.013744 **
sybioa	-1.126e-01	2.727e-02	-4.129	4.12e-05 ***
genefa	4.770e-02	2.698e-02	1.768	0.077531 *
teenpa	4.980e-02	2.535e-02	1.964	0.049938 **
gedua	-4.519e-02	2.997e-02	-1.508	0.132137
fuela	-7.886e-02	3.907e-02	-2.019	0.043950 **
genda	-2.107e-01	1.334e-01	-1.580	0.114699
edua	-4.276e-02	2.328e-02	-1.837	0.066699 *
emplya	-2.243e-01	1.494e-01	-1.501	0.133754
ideologya	1.298e-01	7.763e-02	1.672	0.094981 *
time2	9.040e-02	3.684e-02	2.454	*0.014409 **
WTP: 566.0954				
***Significant at 1% Level, **Significant at 5% Level, *Significant at 10% Level				

Table F.1: Characteristics of Participants Who Would Like to Change Their Mind have effects on the decrease of changing time.

Appendix G

Derivation Process of Equations (4.20), (4.21) and (4.22)

Prove: For $Z_i = x_i'\beta + \epsilon_i$, $\epsilon_i \sim N(0,1)$, $\beta \sim p(\beta)$,if the prior distribution is normal, $p(\beta) \sim N(\beta_0, S_0)$, the full conditional distribution of β is also normal,then $\beta/Z \sim (B, V)$, $B = V(S_0^{-1})b + x'Z$, where $v = (S_0^{-1} + x'x)^{-1}$.

$$\begin{aligned} p(\beta \mid Z) &= p(\beta, Z)/p(Z) \\ &\propto p(Z \mid \beta)p(\beta), \end{aligned} \tag{G.1}$$

so

$$
\begin{aligned}
p(\beta \mid Z) &\propto exp\frac{1}{2}[(Z - x\beta)^T(Z - x\beta) + (\beta - b)^T S_0^{-1}(\beta - b)] \\
&\propto Z^T Z - Z^T\beta - x^T\beta^T Z + \beta^T x^T x\beta + \beta^T S_0^{-1}\beta - b^T S_0^{-1}\beta - \beta^T S_0^{-1} b + b^T S_0^{-1} b \\
&\propto -2Z^T x\beta + \beta^T x^T x\beta + \beta^T S_0^{-1}\beta - 2b^T S_0^{-1}\beta \\
&\propto \beta^T(x^T x + S_0^{-1})\beta - 2(Z^T x - b^T S_0^{-1})\beta,
\end{aligned}
\tag{G.2}
$$

assume $V = (S_0^{-1} + x^T x)^{-1}$ and $B = V(S_0^{-1} + x^T Z)$

$$p(\beta \mid) \propto (\beta - B)^T V^{-1}(\beta - B) - B^T V^{-1} B, \tag{G.3}$$

so

$$p(\beta \mid Z) \propto exp\frac{1}{2}(\beta - B)^T V^{-1}(\beta - B) \tag{G.4}$$

so

$$p(\beta \mid Z) \propto\sim N(B, V). \tag{G.5}$$

Appendix H

Parameter MCMC Simulation Trace Plot

The simulation from Albert and Chibs method:

The simulation from Holmes and Held method:

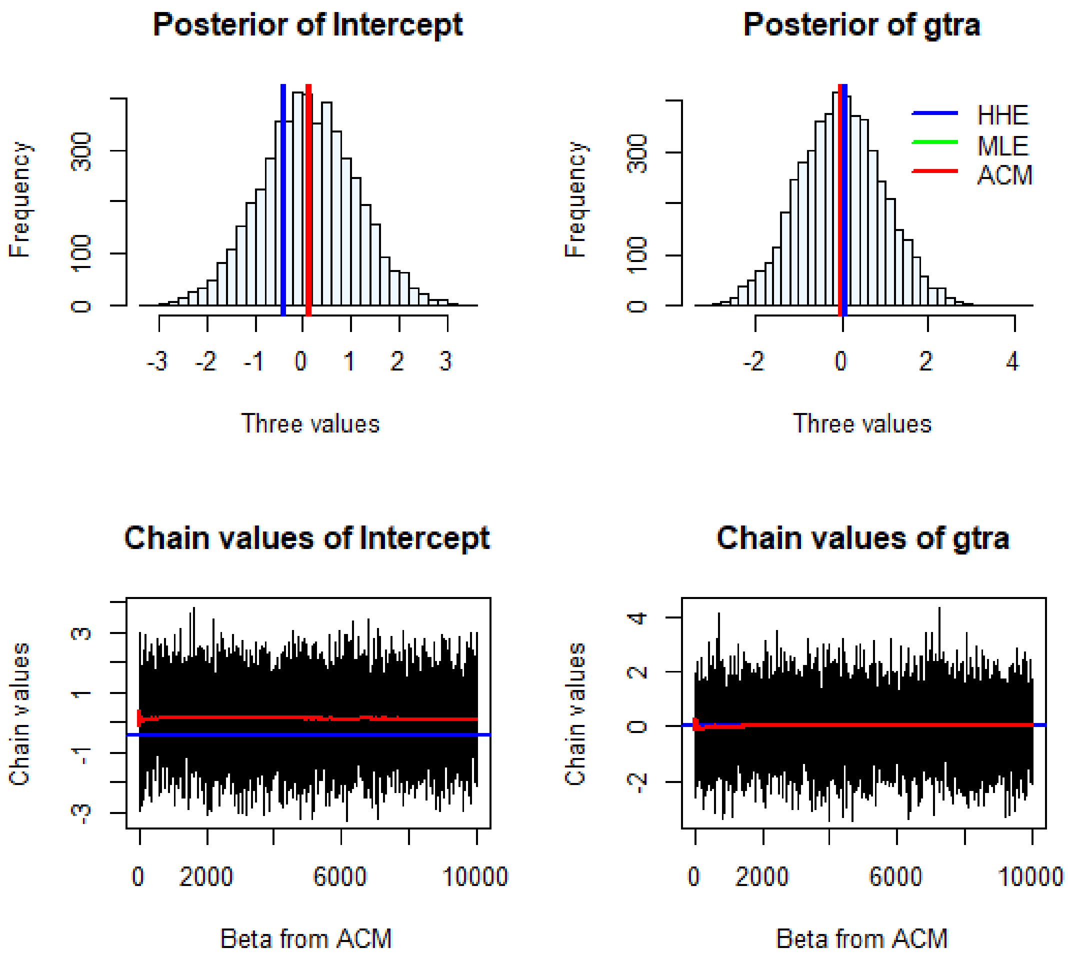


Figure H.1: Parameter 1 and 2 from ACM

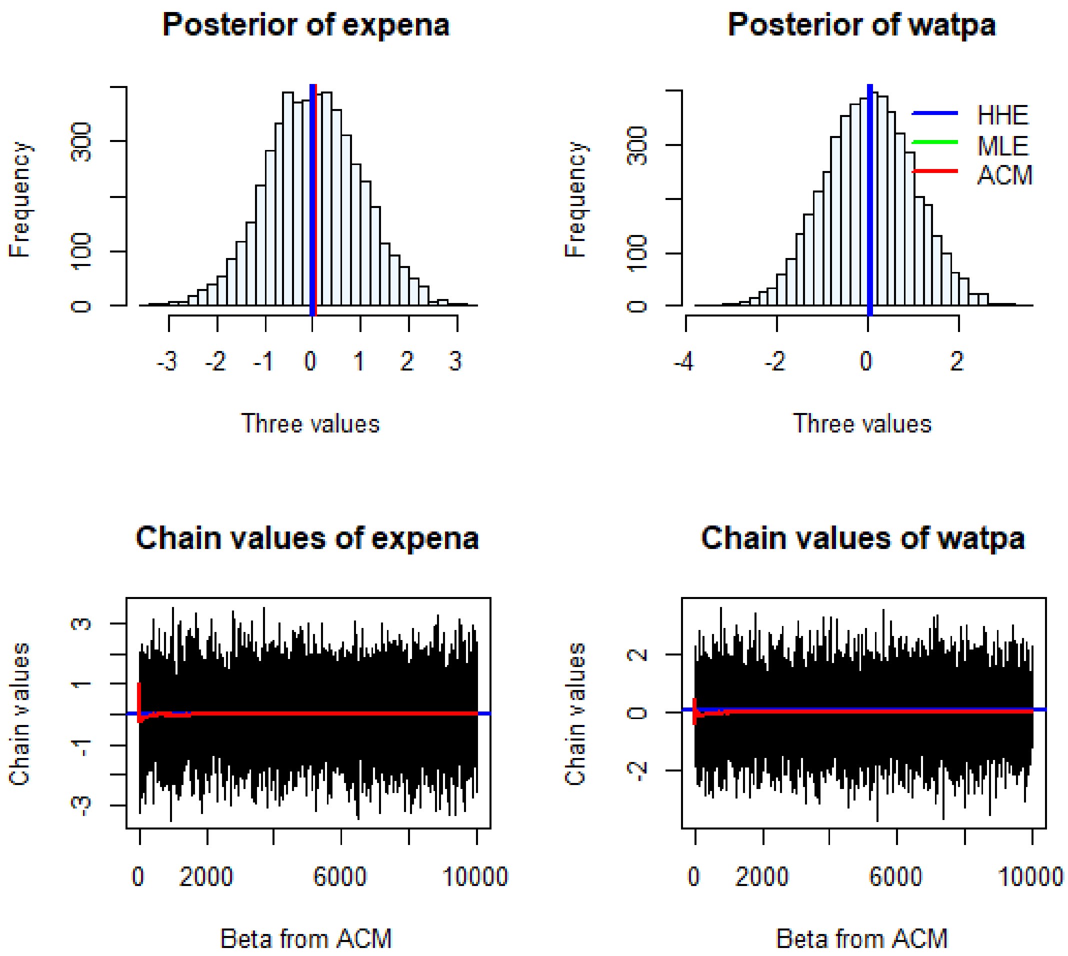


Figure H.2: Parameter 5 and 6 from ACM

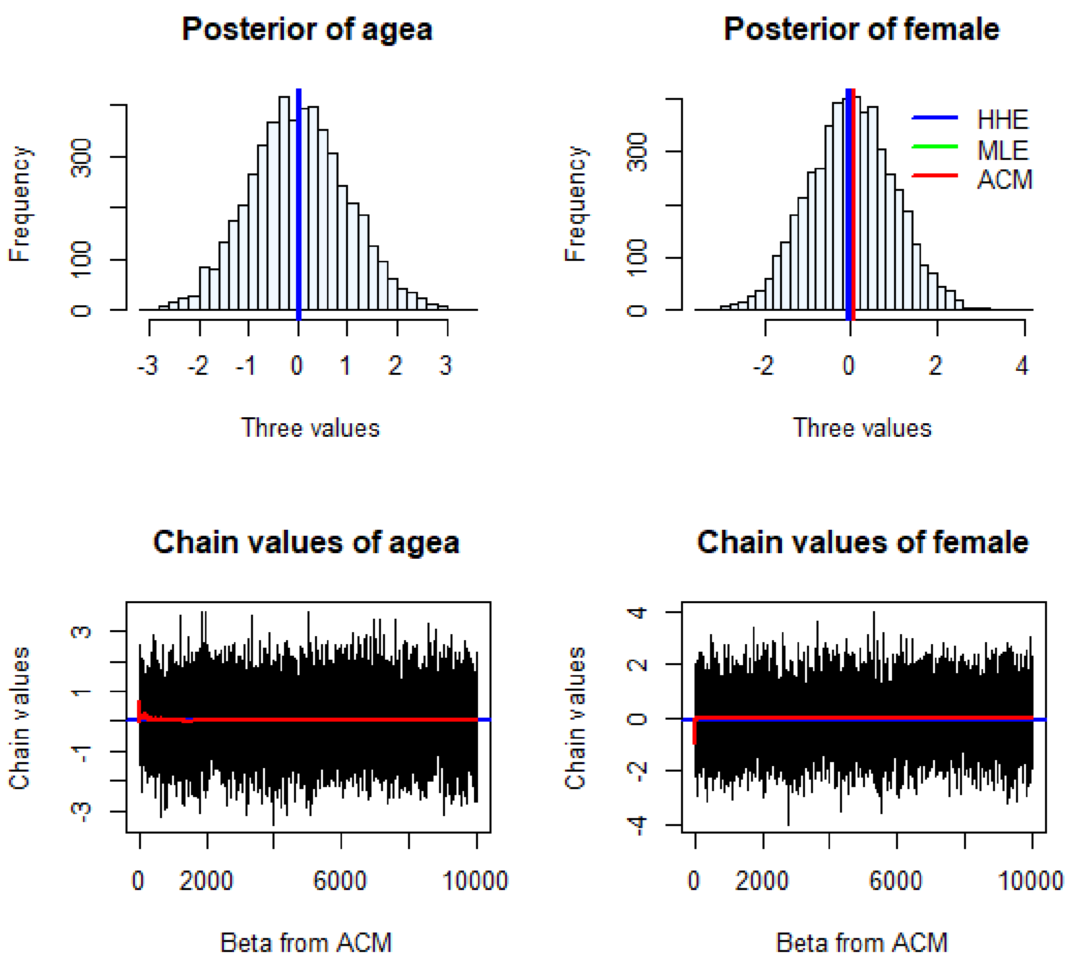


Figure H.3: Parameter 7 and 8 from ACM

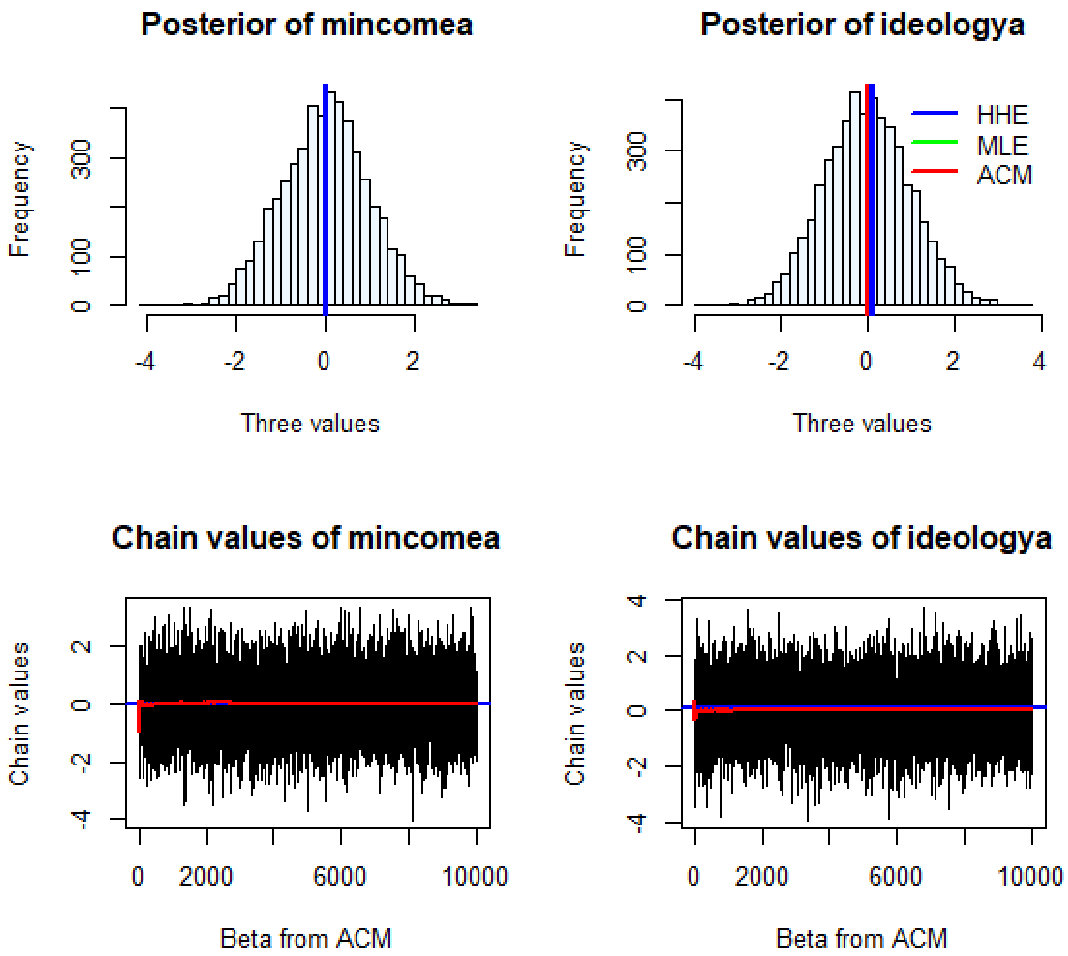


Figure H.4: Parameter 9 and 10 from ACM

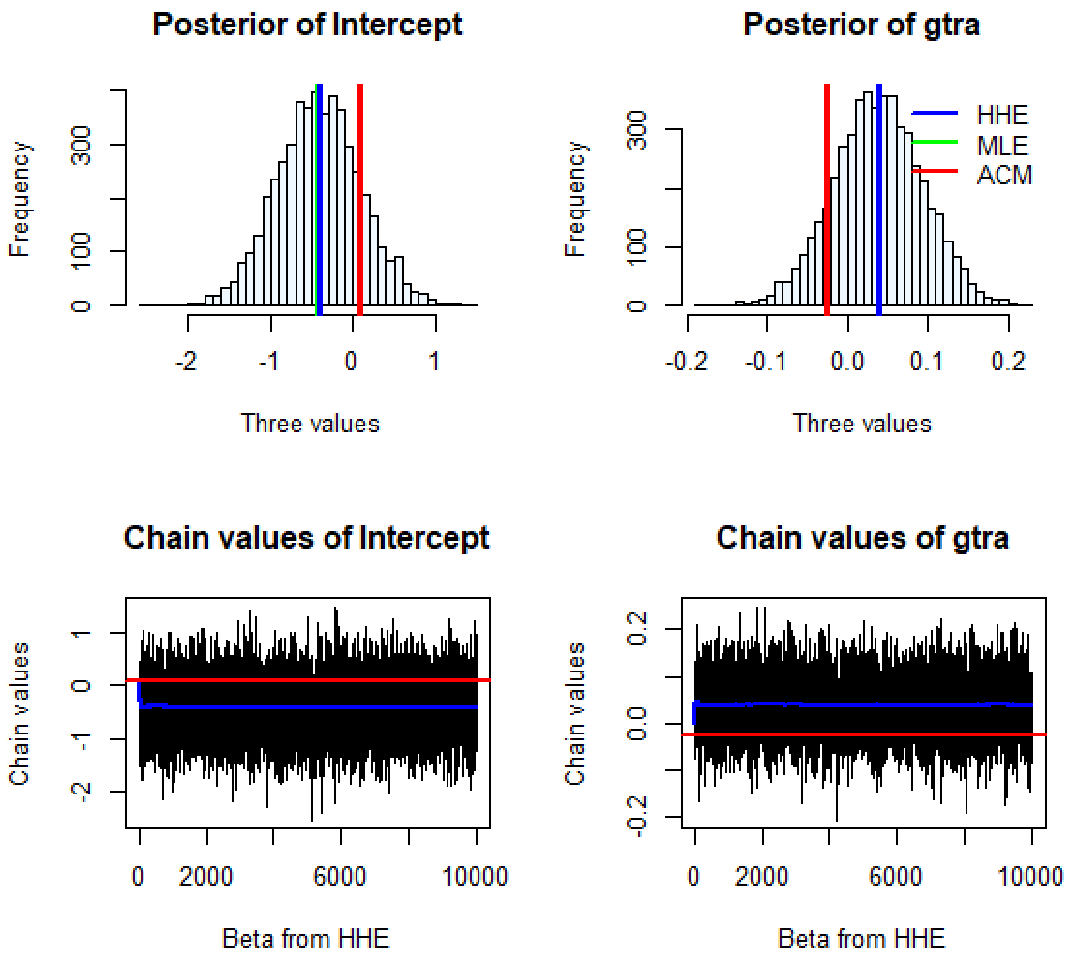


Figure H.5: Parameter 1 and 2 from HHE

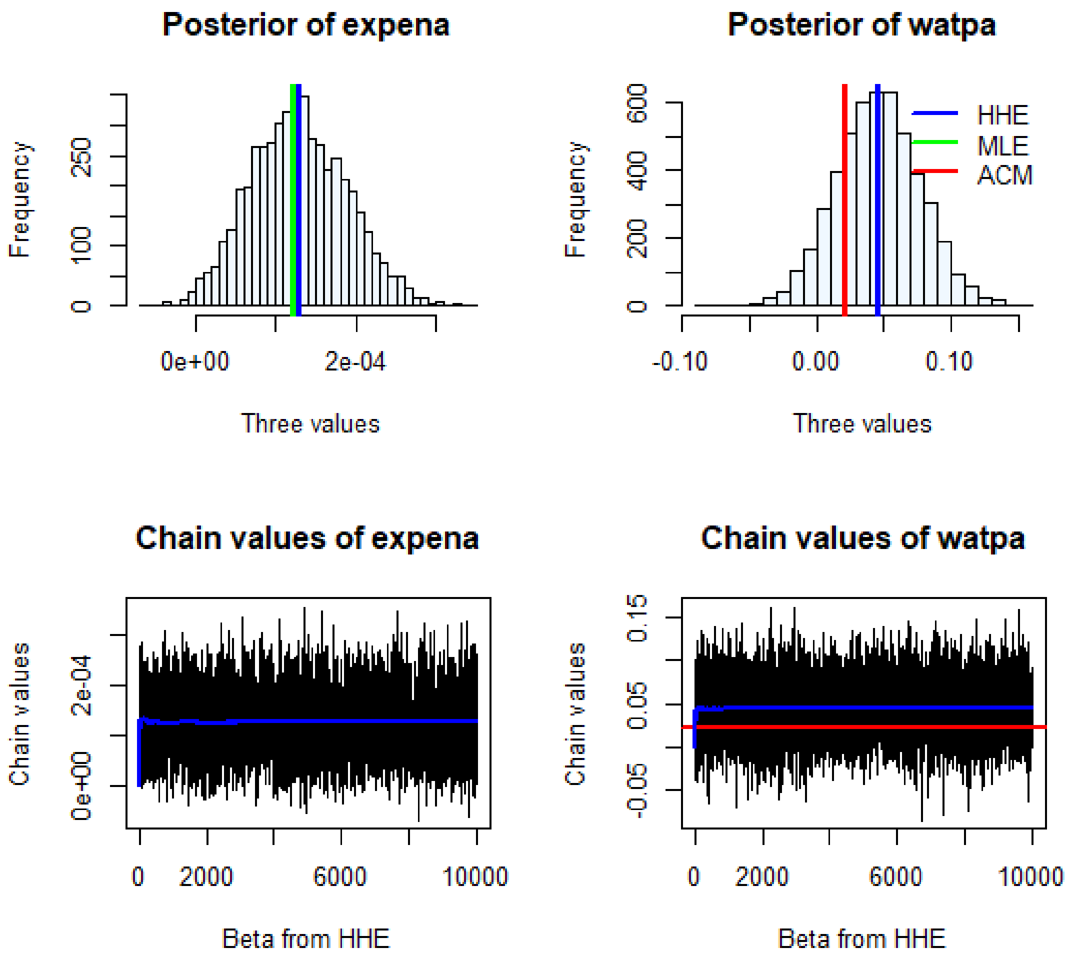


Figure H.6: Parameter 5 and 6 from HHE

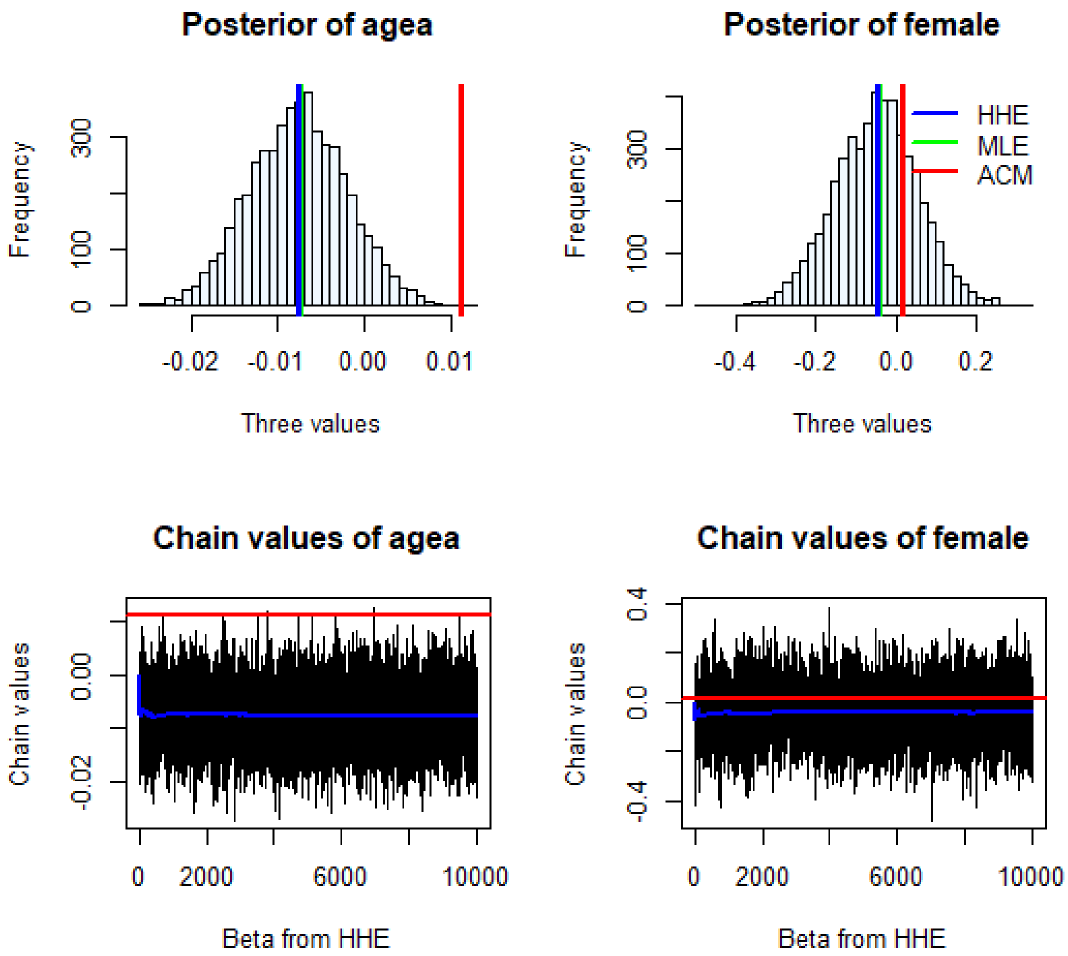


Figure H.7: Parameter 7 and 8 from HHE

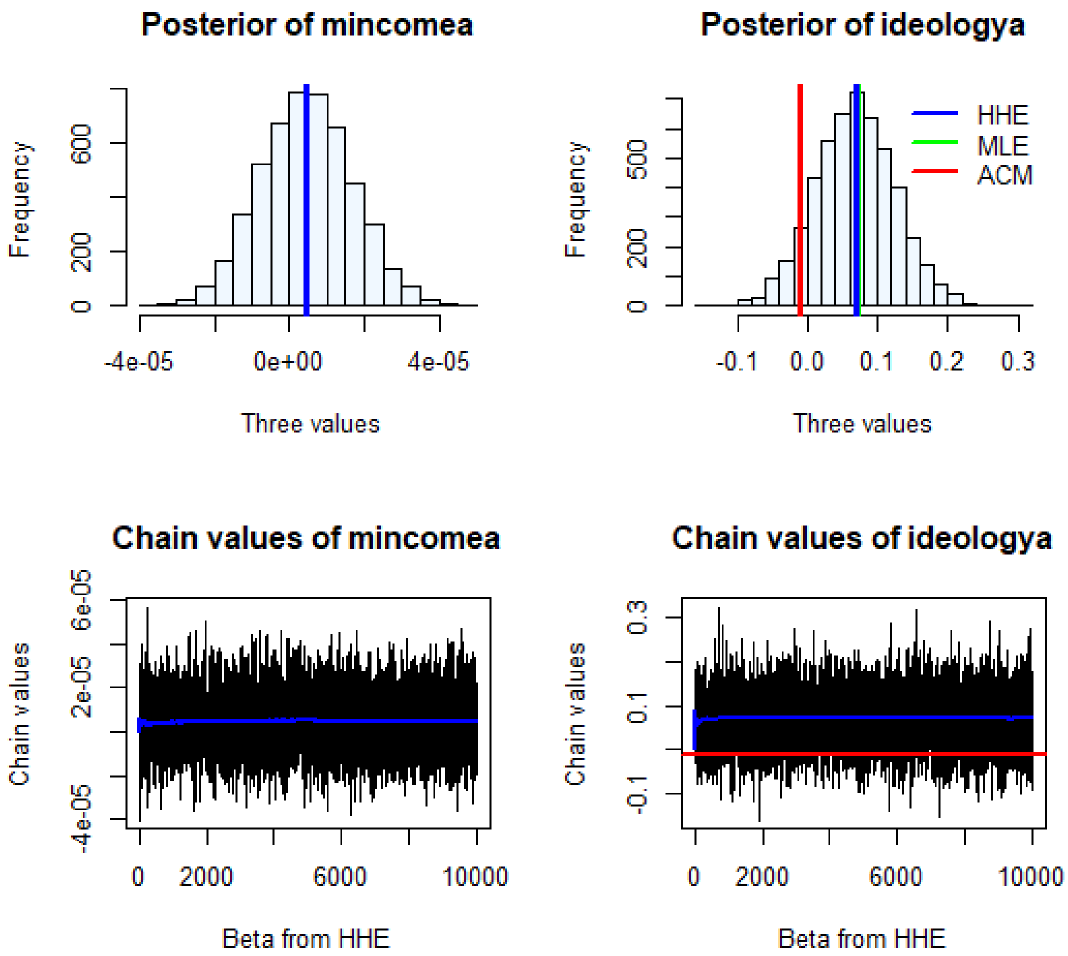


Figure H.8: Parameter 9 and 10 from HHE

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