Abstract

JI QI. Benefits, Costs and Carbon Abatement of Building Efficiency Standards in China. (Under the direction of Dr. Michael Roberts).

In response to rising energy prices, and possibly in an effort to curtail climate change, China's central government recently implemented national Building Energy Efficiency (BEE) standards in order to reduce the energy consumption and carbon emissions relative to GDP. In 2005, China set efficiency targets in its 11th Five-Year plan that required newly constructed buildings to be 50 percent more efficient than buildings constructed in the 1980s. In subsequent years, the great majority of provinces improved building efficiency in accordance with the new standards but different stringencies were adopted in different provinces at different times. In this thesis I exploit differences in timing and stringency levels coupled with province-level panel data on building construction costs to estimate the costs of implementing the new efficiency standards. Using these cost estimates, I evaluate the net present value of investments stemming from BEE change for 15 provinces located in northern part of China. I also evaluate the implicit cost of carbon abatement associated with these investments. I find investment tied to the 50 percent and 65 percent energy reduction standards increased construction costs by 9.2% and 19.4% respectively. The net present values of these investments depend on (a) the expected future path of energy prices; (b) the marginal value of carbon abatement; and (c) the rate at which future energy and carbon savings are discounted to the present. Over a wide range of plausible values for these three factors I find the 50 percent standard had a positive net present value for all 15 provinces in northern China. This is true even if the value of carbon emission abatement is set to zero. To illustrate the whole tradeoffs,

I develop a carbon abatement cost curve spanning both efficiency standards and all provinces. This curve shows the cost of carbon abatement in northern China was negative, even if the discount rate is assumed to be 8% and energy prices are not expected to rise.

Benefits, Costs and Carbon Abatement of Building Energy Efficiency Standards in China

by
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Biography

Ji Qi was born in a Chinese city Chanchun, popularly known as the City of Car. He is the son of Qi Guohua and Fei Richen. He attended Jilin Province Experimental High School in Changchun, China. Following his graduation from high school in 2005, he was admitted to Zhejiang University where he received his Bachelor of Science degree in Energy and Environment system engineering in 2008. He moved to the United States in 2008 to pursue graduate education in economics in Raleigh, North Carolina.

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1 Introduction

Improving energy efficiency and reducing carbon emission are increasingly important components of policy in China. In 2009, China announced that by 2020 it would reduce its energy intensity of GDP by 40 to 60 percent and carbon emissions intensity of GDP by 40 to 45 percent compared with 2005. China claimed that these targets would be "a binding goal" incorporated into China's medium and long-term national social and economic development plans (China’s state council, 2009).

Much attention is focused on improving building energy efficiency (here after “BEE”), as energy used to heat, cool and light buildings consumes more than 20 percent of final energy consumption in China, and is projected to rise to 25 percent by 2030 (Li, 2008). According to Mckinsey’s estimates, China’s building sector contributes about one fifth of the country’s carbon emissions and will increase by an average of 80 million tons a year to reach 3.2 gigatons by 2030, an amount equal to about 1.6 times of the total carbon emission of EU in 2007. At the same time, China’s building sector has 1.1 gigatons of carbon emission abatement potential, nearly 70 percent of which has a negative carbon emission abatement cost, according to Mckinsey (2006).

BEE standards are the primary policy instrument for influencing the energy efficiency of newly constructed buildings. BEE standards set energy efficiency targets and often require the installation and use of specific types of equipment and materials. The reason standards are so important for energy efficiency is due to China’s unique way of charging for heating services. Buildings and households connected to the centralized heating system pay for central heating based on the heated area of the apartment rather than actual energy use. Furthermore, households cannot control the level of heating use themselves. Holding these institutional features fixed makes BEE standards a crucial factor for energy efficiency. Alternatively, China could like increase energy efficiency significantly by decentralizing the heating system and charging for energy consumption. Estimating the costs and benefits of such large-scale institutional changes is beyond the scope of this thesis.

The great majority of provinces have region BEE standards that set an energy saving target based on the national BEE standard for newly construction buildings. In recent years, a growing interest in energy security and climate change has increased the policy relevance of BEE standards. In 2005, China central government released new building energy efficiency target in its 11th Five-Year plan. It required new construction buildings to achieve at least 50 percent energy efficiency compared with that of 1980 level. In the following years, individual provinces improved their BEE standards as specified by the 11th Five-Year plan, but were allowed to develop specific terms of the plan locally, and were also given some flexibility as to time of implementation of the standards. As a result, different provinces adopted new standards at different times.

Despite such sweeping changes to residential BEE standards, surprisingly little is known about how BEE standards affect building construction cost in practice and how these costs relate to emission reductions associated with different BEE standards. This study focuses on the costs of constructing new buildings in 15 provinces located in North China where heating service is controlled and operated by local government as social welfare. I examine province-level building construction costs, energy efficiency performance and carbon emission abatement before and after each local government changed their region BEE standard from 2001 to 2008. Compared to the 1980 building energy consumption level, evidence shows that new construction building energy consumption per square meter has declined significantly. In the meantime, buildings construction costs have increased 5 percent-20 percent.

Based on the estimated costs of implementing the standards and the estimated energy savings that resulted from them, I conduct net present value (NPV) analysis of investments made in accordance with the 50 percent energy saving BEE standards and 65 percent energy saving BEE standards. Separate estimates are calculated for each of the 15 provinces located in north part of China under three assumed discount rates (1%, 5%, 8%) and carbon emission values ranging from 0 to 250 dollar per ton. The analysis indicates the 50 percent standard had a positive net present value for all 15 provinces in northern China, even when carbon emission abatement is set equal to zero and the high discount rate (8%) is used.

This study is germane to understanding the broader costs of abating carbon emission. This literature has shown that optimal BEE standards vary cross regions and depends on a variety of factors including increment construction cost (Ri 2009; Wang, 2009), energy price (Li, 2008), and carbon emission price (Mckinsey, 2006). This literature examines the relationship between optimal BEE standards and discount rates (Li, 2009). This literature also projects the carbon emission abatement potential related to BEE improvement (Mckinsey, 2006).

Former evaluations are typically based on case studies using engineering approach that compare building construction cost and energy efficiency performance of a baseline pre-standard-change building to that of a baseline post-standard-change building. While such approach is useful in many respects, it has some of potential limitations. First, data collected from small number case studies cannot reflect the average construction cost and energy performance, across multiple regions. Second, few of former studies consider the discount rate or the net present value when evaluating the BEE improvement. Third, earlier studies do not consider relative carbon emission abatement potential. Moreover, although most of these studies indicate that BEE improvement will benefit China's future, the optimal BEE standard for each region has not been considered.

The research presented in this thesis attempts to fill these gaps in several ways. First, this study uses data of province-level construction cost data from China's fixed asset investment statistical year book (2001-2008) and China building energy efficiency report to analyze building construction costs before and after the BEE standard change. New construction building energy efficiency performance on heating, cooling and lighting will be examined for energy efficiency part of thesis. Second, NPV analysis of investment on 50 percent energy saving BEE and 65 percnt energy saving BEE is estimated for all 15 provinces using a range of discount rates. In addition, the NPV analyses consider a schedule of carbon emission reduction values ranging from 0 to 250 US dollar per ton. These values are also presented in the form of a carbon emission abatement cost curve. The cost curve considers both the 50 percent and 65 percent percent efficiency standards across all provinces and aggregates to show how total carbon emission abatement potential vary with the per-ton cost of carbon abatement.

The organization of the thesis is as follows. Section 2 provides the background information of China building sector, China heating service system and China BEE standards. Sections 3 and 4 describe the data and regression analysis. Section 5 presents estimates of NPV of investment on BEE improvement for each province under a variety of specifications. Section 6 presents the carbon emission abatement curve. Section 7 concludes the key findings and discusses the future study.

2 Background

2.1 Context of China's building sector

The Chinese residential building sector consumes approximately 20 percent of the country's final energy and this number is expected rise by 1.1 percent every year (Li, 2008). With the rapid growth of economic development and continues urbanization, China is experiencing a peak of building construction. Meanwhile, a lot of existing buildings are being demolished and are being replaced by new ones the life cycle of buildings in China is very brief compared with that of buildings in industrialized countries. From 1990 to 2002, the annual growth rate of the building sector was as high as 15.5 percent, making this industry one of the most dynamic sectors of the country's economy (German Development Institute, 2008).

According to the World Bank's estimates, China's residential buildings consume between 50 to 100 percent more energy for space heating compared with buildings in similar cold climates in Europe or North America, while still offering far less comfort. Several studies have shown that by enhancing the BEE standards, China can reduce its energy consumption and carbon emission at low cost (Ri 2009; Wang, 2009). Accordingly, China's potential to reduce energy consumption through enhancing BEE is enormous.

In addition, the potential benefit of enhancing BEE is mitigating climate change. Currently, China energy production is based on burning coal and other fossil fuels, which are primary sources of carbon emissions. Therefore, China carbon emission will be abated with the reducing of its energy consumption.

2.2 Heating and cooling in North China

In the Northern climate zones ("very cold" and "cold zone") most heating is centralized and provided by the local government as social welfare. These centralized systems connect most buildings in urban areas and almost all the newly constructed buildings to a centralized furnace. Because individual buildings do not have furnaces, there is no building-specific monitoring of energy consumption. In cold zone provinces, like Beijing and Tianjin, about 80 percent of all apartments have access to coal-fired central heating. Liaoning, in very cold zone, for instance, almost 100 percent of the newly constructed apartments are connected to the central heating system.

Buildings and households connected to the centralized heating system pay for central heating based on the heated area of the apartment rather than actual use. Prices per square meter, shown in Figure 1, are fixed and vary across provinces. Central heating is only available during the heating season and is provided independent of outdoor temperatures. For example, in Beijing central heating is operated from 15 November to 15 March. In China, central heating supply systems are still one-pipe heating systems where heat cannot be controlled individually. Room temperature depends on the location of the apartment and temperature and can only be altered by opening and closing windows. In China, heating costs amount to about 15–30 percent of individual household incomes (World Bank, 2001). The employer either pays the heating bill directly or transfers a subsidy for heating to employees.

Energy costs for the remaining individual heating systems are billed according to consumption. In general, they are more expensive than central heating, but they have the advantage that the room temperature can be regulated individually and that heating systems can be turned on before or after the heating periods.

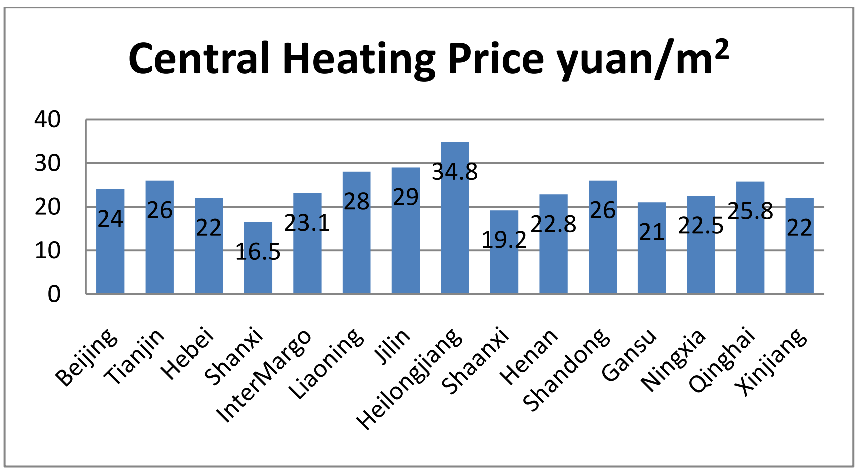

Figure 1Central Heating Price

On the other hand, cooling is not provided centrally in Northern China. In some parts of north China, during the hot summer, air conditioners are being increasingly used more and more. Electricity costs for cooling with air conditioners have to be paid directly by the households according to consumption.

In China’s 11th Five-Year Plan for National Economic and Social Development (2006-2010), the Chinese government set the target to decrease new construction buildings energy consumption at least by 50 percent. The building sector is considered to be one part of the general energy strategy. Because of the unique way of charging households for heating services such that the heat area and households cannot control the heating use themselves, BEE standards the crucial factor for energy efficiency.

2.3 China BEE standards

BEE standards are the command-and-control measures of building construction in China. BEE standard regulate goals and technologies buildings must reach and comply with. BEE standards set energy efficiency targets and often require the installation and use of specific types of equipment. In China, there are national as well as regional standards and standards for public and commercial as well as residential buildings. BEE standards only refer to newly constructed buildings.

2.3.1 National standards

According to the "Standard of Climatic Regionalization for Architecture" (GB 50178-93), China is divided into five climate zones: "very cold", "cold", "hot summer and cold winter", "hot summer and warm winter" and "warm". Starting in 1986, the Chinese government issued several standards referring to BEE in these different climate zones.

In 11th Five Year Plan, China's central government set the target for new construction buildings to reduce energy consumption at least by 50 percent based on the energy consumption performance of building built in 1980s. Thereafter, the "Thermal design code for public buildings" (GB 50189-2005) was approved in 2005, which contains the target of a 50 percent reduction in heating, cooling ventilation, air conditioning and lighting energy. After 2005, in the following years, local governments released their own region BEE standards which require 50 percent energy saving compared with building built in 1980s, for new construction residential buildings.

2.3.2 Regional standards

In China, local governments can set their own standards that differ from the national standards so as long as they are more stringent. One example is the 65 percent standard in Beijing and two other municipalities, which exceeds the national one of 50 percent (energy-saving design standard for the heating of residential buildings DBJ 01-602-2004, energy-saving design standard for the heating of public buildings DBJ 01-621-2005). Apart from the national standards, there are specific standards for the different climate zones in China:

The "Energy Design Code for Heated Residential Buildings" (JGJ 26-86) of 1986 was issued for the very cold and cold zones. The goal was a 30 percent decrease in energy consumption relative to "base buildings" constructed in 1980-81. The standard was revised in December 1995 and renamed "Energy conservation design standard for new heated residential buildings" (JGJ 26-95). The new increased energy saving target was 50 percent. However, due to lax monitoring and enforcement of standards by the government, only 5 percent buildings constructed after 1995 meet JGJ 26-95 standard. The average energy efficiency performance of building that built under JGJ 26-86 7.2 percent below those built in 1980-81, and those built under JGJ 26-95 use 37 percent less energy that those built in 1980-81 (China architecture research group, 2005). This situation changed after 2005, since local governments of northern China provinces successively announced their own local BEE standards and related regulations. Monitoring and enforcement of standards now appears more vigorous. Design and construction of new buildings that do not meet local BEE standards are prohibited and newly buildings that do not pass energy efficiency examinations are not be allowed to be sold on the market.

3 Data

I use province-level building construction data from China national yearly statistic census and each province's yearly statistical publication combined with detailed information on building energy consumption from China 11th Year Plan, China Building Energy Efficiency design standards, China Ministry Housing and Urban-Rural Development and China development and reform commission.

3.1 Building Construction Cost Characteristics

Building construction cost characteristics come from China's fixed asset investment year book and the China statistical year book. These data resources are a comprehensive inventory of building construction costs, new construction area and building floor area in each year and each province of China. Much of the information in China's fixed asset investment year book and China statistical year book come from China's national Statistical Bureau, each Province's Statistical Bureau and related official departments, comes from a form completed annually by all city and construction companies.

The analysis focuses on the buildings built between 2001 and 2008, between 2000 census and the 2009 census. China's central government released its 11th five year plan, which gave the new construction BEE targets, in 2005. Then, local governments improved their BEE standard at various different times in the subsequent years. Building designs do not pass the energy efficiency test will not issue the construction permit and residential buildings that do not pass the energy efficiency examine cannot be sold in the market.

Evidence shows that construction cost in each province increased visibly in the year when province announced to implement new BEE standards. The incremental cost for new construction buildings achieving 50 percent energy efficiency will be about 200 yuan per square meter (Wang, 2009). Cases studies of construction cost of newly construction buildings reaching 50 percent energy efficiency increase 5 percent-15 percent compared to buildings without BEE standards. Figure 2 shows examples of how construction cost increased as BEE standards changed. Beijing announced in 2006 that newly constructed buildings would achieve 65% energy efficiency compared with the 1980 level. And the average construction cost per square meter increased by 267 yuan after new BEE standard was set. Shandong and Intermargo announced that newly construction buildings must meet a 50 percent energy efficiency standard in 2005 and average construction cost per square meter increased 129 and 123 yuan respectively in the same year.

Public buildings are excluded from the BEE standards because they are built for different purposes, such as schools, hospitals and shopping malls, so there are no uniform materials and building techniques that can be easily specified. The relevant laws for public buildings therefore are not as complete as residential buildings. For example, a big shopping mall cannot use the same BEE standards as the school. Moreover public buildings do not have a comparable baseline to calculate the energy consumption.

An advantage of using province-level data is broad geographic coverage. Province-level data provide information for the building construction cost that reported by more than 95 percent construction companies in each province, even small companies with small little construction area are represented proportionally in the sample. Use of long-term province-level nature data rather than real case studies as most relative research can exclude uncertainties like construction process cost and specific design, or indirect costs that may be overlooked in case studies.

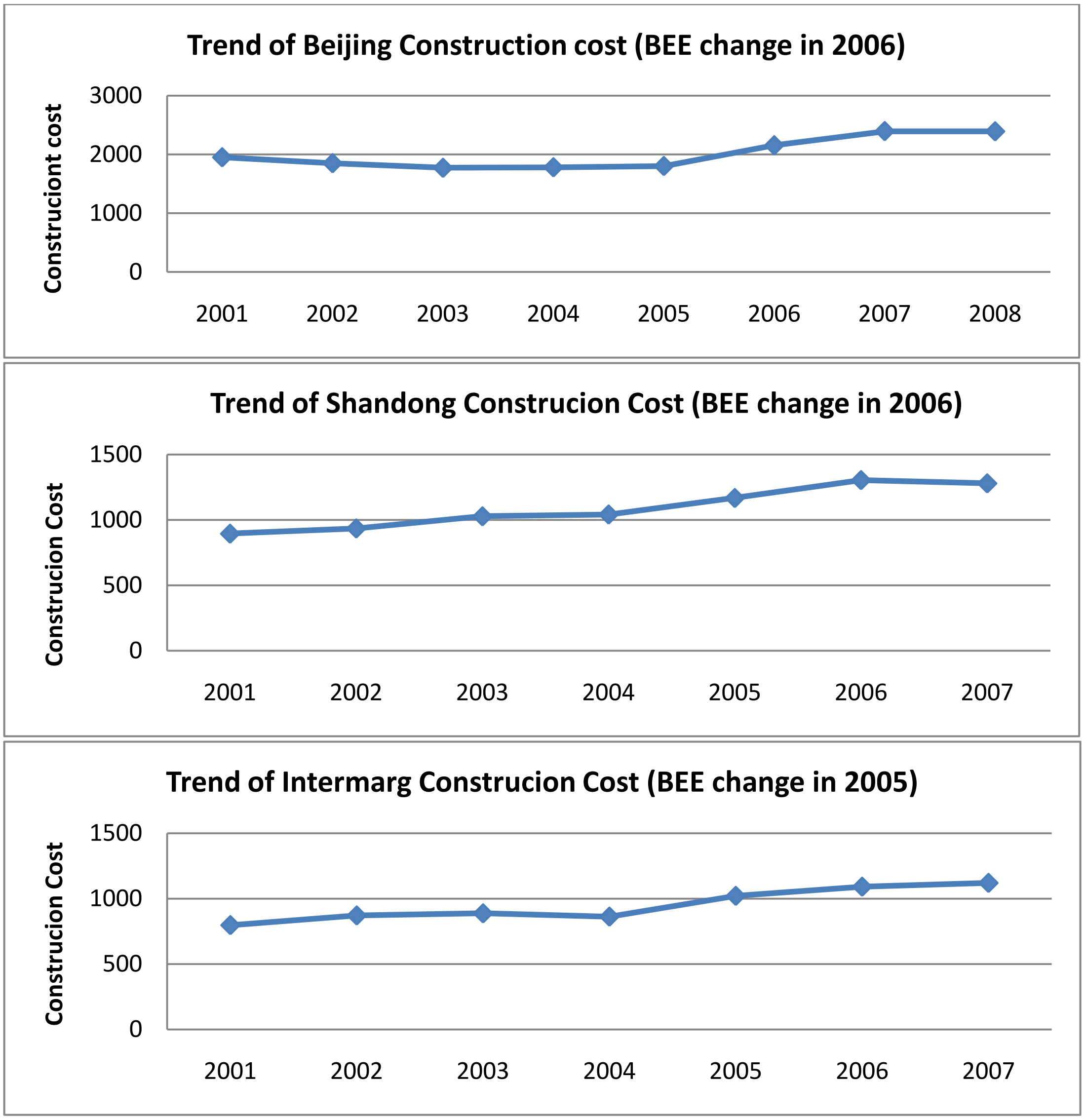

Figure 2 Trend of building construction cost (2001-2008)

3.2 Building Energy Consumption Characteristic

The building energy consumption characteristic used in this analysis comes from China Building Energy Efficiency design standards (JGJ26-95 and JGJ26-86) and New Construction Building Energy Consumption Investigation conducted by Tsinghua University. Energy consumption characteristic include coal consumption for heating, cooking per square meter, electricity consumption for lighting, cooling and appliance per square meter.

China Building Energy Efficiency design standard (JGJ26-86) is the baseline energy consumption that used for calibrating all other BEE standards. JGJ26-86, established by China's central government, is the energy consumption standard for buildings built in 1980-1981. This standard established, by climate region and season, a specific amount of coal needed for heating and lighting for each province. Subsequent standards were set in relation to the 1980-81 standards. In JGJ26-95, the central government set a target to achieve a 50 percent reduction in energy use relative to the 1980-1981 building energy consumption level. The standards also set heating coal consumption quota for each province. Data on electricity consumption for appliances are excluded because the energy efficiency for appliances is not included in BEE standards.

4 Regression Analysis

The change of BEE in each province, the timing of change and the data on building construction cost provides an opportunity to examine the effect of BEE standard improvement on building construction cost. This section describes our empirical strategy and results. My data come from the observations of province-level average building construction cost of 15 provinces between 2001 and 2008.

The regression models, described in section 4.2, use standard panel regression techniques that include year and province fixed effects. In a model with these fixed effects, identification of the effect of BEE standards changes on building construction costs follows from differences in the timing of BEE standard implementation across provinces. The critical exogeneity assumptions rest on the idea that the timing of standard implementation is not associated with time-varying heterogeneity across regions. In other words, the timing of standard implementation cannot be associated with other, unobserved factors that may have otherwise caused costs to rise or fall around the time of implementation. I therefore provide background information in section 4.1 on province-level implementation of building standards. While the exogeneity assumption is not testable, the nature of the process that gives rise to differences in timing does not suggest any obvious cost-related factors that would confound the regression-based estimates that follow.

4.1 Timing of Local BEE Change

Figure 3 shows the timings of local BEE change. The central government sets the efficiency target while the timing of local BEE change and detail work is decided by local governments.

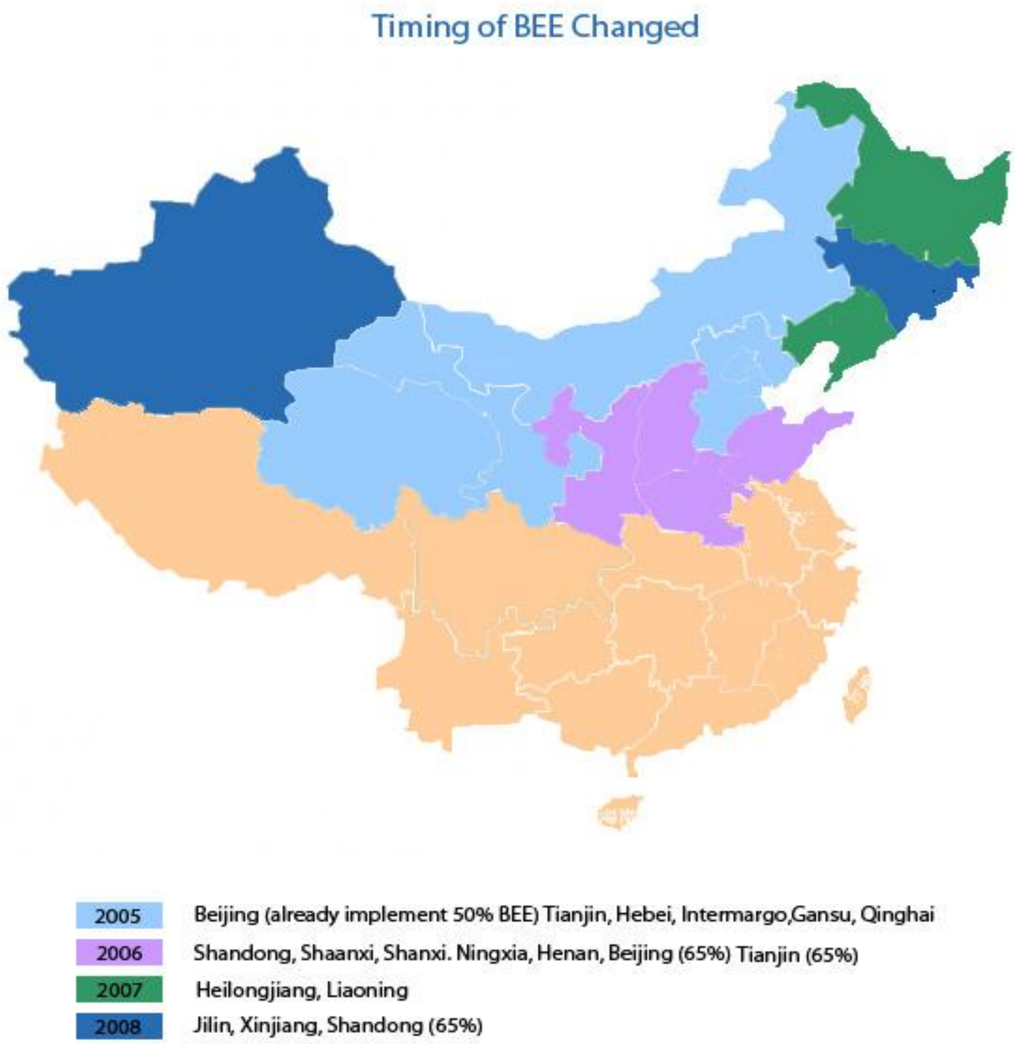

Figure 3 Time of BEE Changed

The political system of China is centralized organization, characterized by that central government that formulates major national policy and local government implement it in details. And in this process, local government can develop specific local policy, including timing to implement, based on central policy, local condition and local characteristics. While, China is a large country with a large population, its economic development is unbalanced and varies cross regions. Therefore, central government policies set broad guidelines that cannot be implemented mechanically by local government. In the case of BEE standards change, the central government set the national BEE standard and then local governments had to implement the policy through local political processes. Local governments therefore decide the specific standards, laws and auditing systems used in each province. The timing of BEE standards basically follows from political process takes time and can vary across regions,. Timing of BEE change is basically decided by how long the political process takes. For example, Beijing, the capital of China, change its local BEE standard to 65 percent BEE in 2006 follow the central government, since Beijing has relative complete BEE laws, audit system and human resource. In contrast, Xinjiang do not have any BEE standard until 2005, hence it takes much longer for Xinjiang to set up the BEE system. Until 2008, Xinjiang changed its local BEE standard to 50 percent energy efficiency BEE standard.

In addition, we examined the relationship between the timing of BEE change and average building construction cost before national BEE change to see whether the timing of local BEE change correlated with local building construction cost before national BEE change. From Figure 5, we can see the trend in building construction cost compares to BEE adoption timing looks random. This result also provides evidence to support the assumption the BEE adoption is exogenous.

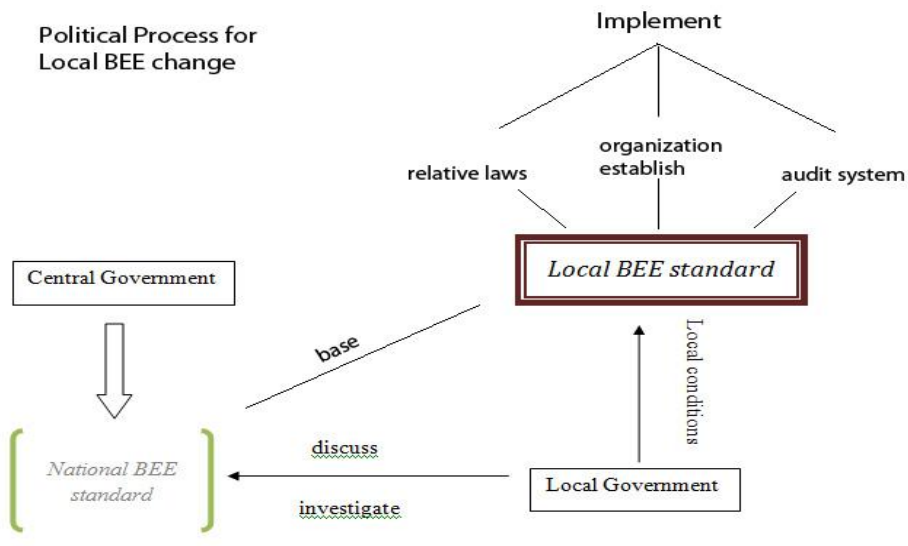

Figure 4 Political Process for BEE Implement

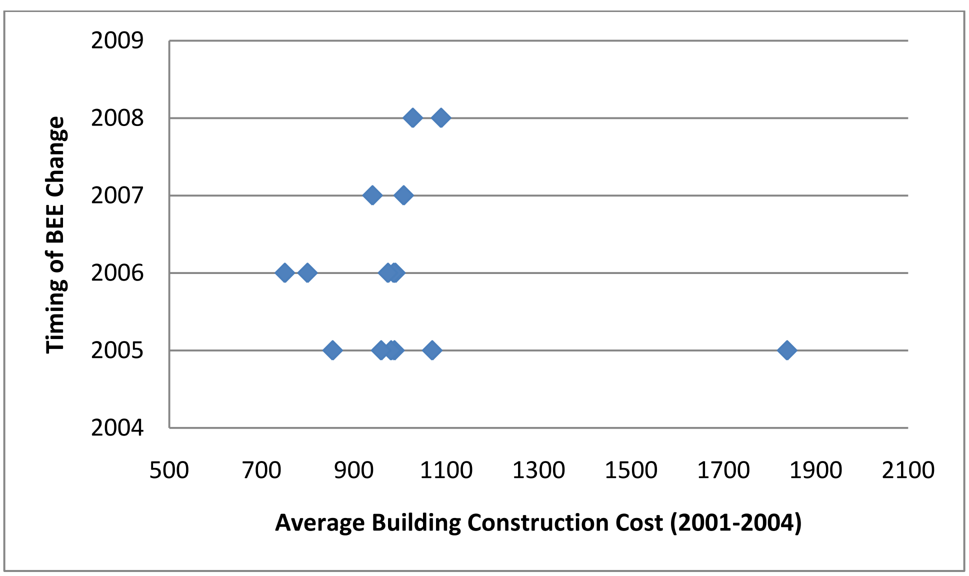

Figure 5 Timing of BEE Change V.S. Average cost

4.2 Estimation Models

I begin with a standard panel regression model to estimate the effect of BEE change on construction cost with linear regression models of the form

$$\ln cost_{it} = Province_i + Year_t + \gamma_1 \text{BEE50\%} + \gamma_2 \text{BEE65\%} + \epsilon_{it} \tag{1}$$

$$cost_{it} = Province_i + Year_t + \gamma_3 \text{BEE50\%} + \gamma_4 \text{BEE65\%} + \epsilon_{it} \tag{2}$$

Where the dependent variables, ln $cost_{it}$ and $cost_{it}$ are the natural log of building construction cost and real construction cost respectively; *i* indexes province; *t* indexes year; $Province_i$ is a dummy variable for each of the 15 provinces that locate in north China. It controls time constant region-to-region shocks in building construction cost, such as local labor price, local price-level, and other local construction operation fees; $Year_t$ is a dummy variable for each of years (2001-2008) that controls for year-to-year shocks common to all provinces, such as raw material price change and price inflation. I have estimated province and year fixed effects to remove any kind of collinearly problem may exist between region characteristics, time period and building construction cost change during this particular time period. BEE50% and BEE65% are indicator variables for whether 50 percent BEE or 65 percent BEE standard be implemented; ϵ_{it} is a normally distributed error term, which may include some unobserved factor that can affect the construction cost.

The critical assumption is that the error is not correlated with BEE standards conditional on the fixed effect controls (i.e., the timing of standards implementation). Here I discuss some possible sources of error so that readers can judge the plausibility of this key assumption. First is the efficiency of the construction management and the weather during the construction. Because labor cost and materials cost are big part of building construction cost, better management performance may improve the construct efficiency and lower the cost. Second is the weather condition during the construction period, if buildings are constructed during some bad weather condition like snow or big wind, the construction period will be longer, as a result, the cost would be higher. Third is the data collection issue. The building construction data are reported by the China fixed asset year book. However, I do not know exactly how the survey is conducted. Therefore if there are some possibilities like the companies overstate or understate their cost, it may affect the report construction cost. Fourth, I assumed the BEE standards are complied after local governments change the BEE standard. Although, local governments forced new constructed building to implement BEE standard and those do not implement BEE standard cannot be sold in the market, I still cannot rule out the possibility few of the new construction building do not fully implement local BEE. However, it is not clear how these various unobserved factors might be correlated with the timing of BEE changes.

The estimates of γ_1 and γ_2 are of primary interest, as they capture the relative difference in building construction cost between provinces that implemented BEE standard with provinces that do not implement BEE standard in given year. Estimates of γ_1 and γ_2 more than zero would, for instance, are consistent with the BEE improvement causing an increase in building construction cost. In a more flexible specification, Model (3), I ruled out the year dummies to measure the relative difference in building construction cost between provinces that implemented BEE standard earlier with those implemented BEE standard later. Further, I test the specification, Model (4) without province dummies to see relationship between the construction cost level and BEE adoption timing. I report these results in table 1.

$$\ln cost_i = Province_{\mathrm{i}} + \gamma_1 \mathrm{BEE50\%} + \gamma_2 \mathrm{BEE65\%} + \epsilon_{\mathrm{i}} \tag{3}$$

$$\ln cost_t = Year_{\mathrm{t}} + \gamma_1 \mathrm{BEE50\%} + \gamma_2 \mathrm{BEE65\%} + \epsilon_{\mathrm{t}} \tag{4}$$

I further examine models that allow the costs of standard implementation differ across locations due to climate and local level of economic develops. Different regions of China have been developing at different rates and it stands to reason that costs of BEE standards change may also vary across regions. Costs may systematically differ between greater and lesser developed areas due to differences in labor costs or costs of transporting raw materials, or other factors. On the one hand, the effect of BEE change on building construction costs could be greater in more developed areas due to relatively higher labor cost and operation fees. However, it is also possible that the effect of BEE change on construction cost is less due to better transportation system and relatively lower materials transporting costs. Costs may also differ across climates (very cold regions verses cold regions). Common technology of building energy efficiency is wall and ceiling insulation, costs may greater in very cold region due to the thicker walls and ceilings. Nevertheless, it is also possible that the cost may be greater in cold region, because cold region usually have to invest more in design and other technology to achieve the same energy efficiency target than very cold region.

In model (5) and model (6), I exclude the data of some province with 65 percent energy saving BEE standard, because all provinces that implement 65 percent BEE are located in high GDP and cold region. High and low economic develop level region are defined by the level of GDP per capita. Provinces where GDP per capita in 2008 exceeds 20000 yuan are High economic develop level region and less than 20000 yuan are low economic develop level region.

$$\textit{ln Cost}_{it} = \textit{Province}_{\mathrm{i}} + \textit{Year}_{\mathrm{t}} + \gamma \mathrm{BEE50\%} + \theta \textit{GDP*BEE50\%} + \epsilon_{\mathrm{it}} \tag{5}$$

Where BEE 50% is a dummy variable for whether building construction under specific BEE standard; GDP*BEE 50% is the cross effect of developed level and BEE improvement. The estimates of γ and θ are of primary interest. A positive value of θ indicates the investment on BEE improvement cost more in high developed area than low developed area. Results are reported in table 1.

I also divide provinces by very cold region and cold region. The definition of Climate regions is consistent with that given by China develop and reform committee. In the sample, 8 provinces, including Jilin, Heilongjiang, are located in very cold region and the rest 7 provinces less cold region. I estimate the effect of BEE improvement in different climate region using follow model:

$$\ln \text{Cost}_{it} = \textit{Province}_i + \textit{Year}_t + \gamma \text{BEE50\%} + \varphi \textit{Climate*BEE50\%} + \epsilon_{it} \quad (6)$$

Where Climate*BEE50% is the cross effect of climate and BEE improvement. φ is the coefficient of interest. If φ is positive, it implies the building construction cost increase more in cold region caused by BEE improvement.

Lastly, I consider the interaction of 50 percent BEE adoption and average local winter temperature of each province, and the interaction of 50 percent BEE adoption and GDP per capita of each province, to account for heterogeneous variation in costs in a more continuous matter. This model is:

$$\textit{ln Cost}_{it} = \textit{Province}_i + \textit{Year}_t + \gamma \text{ BEE50\%} + \mu \textit{ GDP per Capita\_2001*BEE50\%} + \delta \textit{Aver\_Winter\_Temp*BEE 50\%} + \epsilon_{it}, \quad (7)$$

where *GDP per Capita*BEE 50%* is the cross effect of 50 percent BEE adoption and GDP per capita of each province in 2001; *Aver_Winter_Temp*BEE 50%* is the cross effect of BEE adoption and average local winter temperature. This specification estimates the percentage increase of building construction cost for each province instead of an average percentage increase of building construction cost for all the provinces got from previous models.

4.3 Regression results

Table1 presents the results of the regressions relating building construction costs with implementation of BEE standards changes.

In column (1), the estimated coefficient of BEE standard improvement, γ_1 is positive and it is 0.092. This coefficient gives the estimated proportional difference in building construction cost that occurs with the adoption of BEE 50 percent standard. It implies adoption of 50 percent standard increases the building construction cost by 9.2 percent. The parameter γ_2 measures the effect of the 65 percent energy saving BEE standard on building construction cost, holding all else the same. The estimated value of γ_2 is positive and its value is 0.194. This implies adoption of 65 percent BEE may increases the building construction cost by 19.4 percent, holding all else the same. The p-values associated with these estimates of γ_1 and γ_2 are less than 0.001. Based on the F-test, province fixed effect and year fixed effect are statistically significant. These estimates come from the fixed effect model, which I use as a baseline.

The only difference between model 1 and model 2, reported in column 2 of table 1, is that the first considers the natural log of cost and second uses the level of cost. In the second model the estimated coefficients of BEE standard improvement, γ_3 and γ_4 are 267.37 and 784.38 for the 50 percent and 65 percent standards, respectively. This implies that average building construction cost per square meter will increase by 267.37 yuan when new construction building implement to 50 percent energy saving BEE standard compared with doing nothing and 784.38 when complying with 65 percent energy saving standard. The p-value of γ_3 and γ_4 are also less than 0.001. I compare the residual distribution (see appendix E) and find the model (1) is the more appropriate model.

Column (3) reports estimates obtained without year dummies. This model identifies the effect of BEE standard using only variation in costs over time. The coefficient for 50 percent BEE and 65 percent BEE are 0.135 and 0.258 respectively. Comparing the estimates, I found the BEE change effect on building construction cost is greater when excluding year dummies. The explanation for higher coefficient of BEE change is likely due to a general trend in building construction cost that confounds the effect of BEE standards given the standards were generally in place later in the sample and no in place earlier in the sample.

Column (4) reports the estimates of baseline model excluding province dummies. This model identifies the effect of BEE standards using only variation in costs over the cross section of provinces. The coefficient for 50 percent BEE and 65 percent BEE are 0.126 and 0.35 respectively. The estimates are greater compared with my base model. The main reason for the difference is likely due to Beijing. Beijing had already implemented 50 percent energy saving BEE standard in 2001 and Beijing is the only province that implement 50 percent energy saving BEE before 2005. As the capital of China, Beijing's building construction costs are also much higher compared to the national average. Beijing changed to 65 percent BEE standard in 2006 and it is also the first province that implemented 65 percent BEE standard. To examine the effect of Beijing I repeated all of the regressions while excluding all Beijing observations. Results for most specifications change little; however the estimated

BEE effect declines significantly in the cross-sectional regression that excludes year fixed effects. The results excluding the Beijing observations are reported in table 2. From table 2, we can see the BEE change effect, both 50 percent BEE and 65 percent BEE, are still significant. The coefficient of 50 percent BEE change effect is relative small compare with that in table 1 and the coefficient of 65 percent BEE change is greater, however, the estimates do not change much. The estimates of model 3 and model 4 are very similar.

Column (5) of tables 1 and 2 reports estimates of model 5, which includes interaction effects that allow the estimated cost of the 50 percent BEE standards to vary over high-GDP and low GDP regions. The estimated coefficients indicate the BEE standard increased construction cost 5.7 percent in low-GDP regions and an addition 4.2 percent (9.7) in high-GDP level regions. This can be explained by labor price, construction material price and relative operation fees may be higher in high-GDP level region. Recall that this model excludes observations with the 65 percent standard.

Column (6) reports results from model 6, which includes interactions effects that allow the estimated cost of the 50 percent BEE standards to vary by climatic region (cold and very cold). The estimated coefficients indicate the 50 percent BEE standard increased building costs 5.5 percent in the very cold region and an additional 6.2 percent in the cold region. This result can be explained that cold region may require greater investments, such as thicker walls with more insulation, to achieve the same proportional reduction in energy use.

Because costs of implementing the BEE standard clearly vary across regions, I estimate a model with continuous interactions of the standard with pre-standard GDP and the standard with climate, proxied by the average temperature during the winter months. These results are reported in column (7). The estimated coefficients of the cross effect of BEE standards change and average winter temperature is 0.00231, which indicates that cost of 50 percent BEE standard adoption will increase 0.231 percent as the local winter temperature increase 1 degree. This is consistent with the results from model (6), which suggest the BEE adoption cost is higher in cold region than very cold region. The estimated coefficients of the cross effect of BEE standards change and GDP per capita is 8.14e-6 percent, which means cost of 50 percent BEE adoption will increase 8.14e-6 percent as the local GDP per capita increase 1 yuan. This is consistent with the results from model (5), which indicates 50 percent BEE adoption cost more in high GDP level region than in low GDP level region.

Cost estimates of 50 percent BEE adoption for each province from each model are reported in table 3. Estimates from model (4) are not available because province dummies are ruled out. In addition, in table 4, I report the cost estimates of 50 percent BEE from the regressions excluding Beijing observations.

Table 1 Estimates for BEE change effect

Depend Variable	Model (1) Log of cost	Model (2) Real cost	Model (3) Log of cost	Model (4) Log of cost	Model (5) Log of cost	Model (6) Log of cost	Model (7) Log of cost
Explanatory Variable							
50% BEE	0.092 (0.0155)	267.37 (51.51)	0.135 (0.0106)	0.126 (0.02)	0.057 (0.0189)	0.055 (0.0165)	-0.0307 (0.0283)
65% BEE	0.194 (0.0286)	784.38 (95.06)	0.258 (0.0236)	0.35 (0.0334)	-	-	
Cold Region*50% BEE	-	-	-	-	-	0.062 (0.0164)	
High GDP Region*50% BEE	-	-	-	-	0.042 (0.0176)	-	
50% BEE*Aver_win_temp							0.00231 (0.0008)
50% BEE*GDP per capita							8.14e-6 (2.4e-6)
Province Dummies	Yes	Yes	Yes	No	Yes	Yes	Yes
Year Dummies	Yes	Yes	No	Yes	Yes	Yes	Yes
Observation	120	120	120	120	113	113	113
R-squared	0.9	0.89	0.85	0.66	0.87	0.88	0.89

Note: 50% BEE is the dummy variable that indicates whether 50 percent BEE standard is adopted. 65% BEE is the dummy variable that indicates whether 65 percent BEE standard is adopted. Cold Region*50% BEE is the cross effect of 50 percent BEE standard adoption and cold region. High GDP Region*50% BEE is the cross effect of 50 percent BEE standard adoption and high GDP region. 50% BEE*Aver_win_temp is the cross effect of 50 percent BEE standard adoption and average local winter temperature. 50% BEE*GDP per capita is the cross effect of 50 percent BEE standard adoption and GDP per capita of each province in 2001.

Table 2 Estimates for BEE change effect (excluded Beijing observations)

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)
Depend Variable	Log of cost	Real cost	Log of cost	Log of cost	Log of cost	Log of cost	Log of cost
Explanatory Variable							
50% BEE	0.081	234.64	0.133	0.056	0.054	0.052	-0.0336
	(0.0162)	(54.31)	(0.0111)	(0.0206)	(0.0187)	(0.0162)	(0.0283)
65% BEE	0.211	835.23	0.273	0.28	-	-	
	(0.03)	(100.61)	(0.0305)	(0.0372)			
Cold Region *50% BEE	-	-	-	-	-	0.062	
						(0.0160)	
High GDP*50% BEE	-	-	-	-	0.042	-	
					(0.0172)		
50% BEE*Aver_win_temp							0.002345
							(0.0008)
50% BEE*GDP per capita							8.052e-6
							(2.31e-6)
Province Dummies	Yes	Yes	Yes	No	Yes	Yes	Yes
Year Dummies	Yes	Yes	No	Yes	Yes	Yes	Yes
Observation	112	120	112	112	108	108	108
R-squared	0.87	0.89	0.79	0.65	0.87	0.88	0.87

Note: observations from Beijing are excluded from data.

Table 3 Estimate costs of 50 percent BEE adoption

			Cost of 50 percent BEE adoption			
Province	**Model (1)**	**Model (2)**	**Model (3)**	**Model (5)**	**Model (6)**	**Model (7)**
Beijing	386	267	471	436	505	957
Tianjin	344	267	410	354	430	820
Gansu	243	267	311	155	150	132
Hebei	273	267	349	302	357	277
Heilongjiang	261	267	349	288	157	188
Henan	212	267	277	135	284	208
Intermargo	232	267	297	245	143	73
Jilin	293	267	391	295	172	200
Liaoning	280	267	365	309	168	338
Ningxia	217	267	283	138	133	155
Qinghai	261	267	333	174	160	141
Shaanxi	300	267	383	199	392	319
Shandong	267	267	357	308	366	420
Shanxi	273	267	357	302	366	246
Xinjiang	280	267	374	170	164	221

Note: Cost measure is Chinese Yuan per square meter.

Estimates of Model (4) are not available because of there is no province dummies in Model (4)

Table 4 Estimate costs of 50 percent BEE adoption (excluded Beijing observations)

	Cost of 50 percent BEE adoption					
Province	**Model (1)**	**Model (2)**	**Model (3)**	**Model (5)**	**Model (6)**	**Model (7)**
Tianjin	296	234	438	346	407	801
Gansu	217	234	322	147	142	125
Hebei	238	234	356	294	339	269
Heilongjiang	232	234	356	281	149	179
Henan	189	234	283	128	269	204
Intermargo	202	234	303	237	136	66
Jilin	255	234	399	285	161	191
Liaoning	247	234	381	304	159	319
Ningxia	193	234	283	130	127	146
Qinghai	230	234	340	165	152	133
Shaanxi	261	234	395	185	371	314
Shandong	232	234	356	302	347	405
Shanxi	243	234	356	295	347	237
Xinjiang	243	234	390	161	156	212

Note: Cost measure is Chinese Yuan per square meter

5 Net Present Value Analysis

After China central government released its 11th Five-year Plan, in which the new building energy efficiency target was set, new construction building energy efficiency performance improved. Evidence shows new construction buildings energy consumption has declined significantly. However, at the same time, building construction costs increased. As discussed in section 4, the construction cost increase 9.2 percent from the 1980-81 baseline when implementing the 50 percent energy saving BEE standard and increased 19.4 percent from the same baseline when implementing the 65 percent energy saving BEE standard. Therefore, BEE standard improvement can further reduce energy consumption and the carbon emissions, but this needs more investment. The net present value analysis balances the benefits of future reduced energy costs and carbon emissions against current increases in building costs. If the net present value is greater than zero, the investment is worthwhile; if it is less than zero the additional building costs exceed the present value of future benefits. The net present value is calculated as follows:

$$NPV_i = UFC_i + \sum_{k=1}^{30} BE_i (1+\alpha)^{-k} + \sum_{k=1}^{30} BC_i (1+\alpha)^{-k} , \qquad (5.1)$$

where NPV_i is the net present value of the investment on applying BEE standard i; UFC_i is the upfront cost of BEE standard i or the incremental building construction cost related to the BEE standard improvement; BE_i is the benefit of energy saving related to the BEE standard enhancement; and BC_i is the benefit of the carbon emission abatement related to the BEE standard enhancement; α is the discount rate. The standards (i) considered in this thesis are the 50 percent and 65 percent BEE standards, the province-level costs of which were estimated in section 4. The time horizon is assumed to be 30 years, which equals the average building life time in China.

There is no subscript t for time on BE_i and BC_i because I assume these are expected to remain constant over the 30 year horizon. In reality energy prices or carbon abatement values may increase or decrease over time. The values, however, are highly uncertain and difficult to forecast. For example, prices for coal, which serves as the primary source of heating energy in China, follow a near random walk without drift (Berck and Roberts, 1996). The social value of carbon abatement also remains highly uncertain even today and how this will evolve over time is unclear.

Instead of assuming these values will follow particular trends, I instead consider a range of discount rates. Using a high discount rate and constant energy savings and carbon abatement values in the NPV calculation is equivalent to using a moderate discount rate and assuming energy prices and carbon abatement values will decline. Conversely, using a low discount rate and constant benefit flows is equivalent to using a moderate discount rate and assuming these benefits will rise over time. The discount rate assumptions are discussed further below.

5.1 Upfront cost associated with BEE improvement

BEE standards set energy efficiency targets and often require the installation and use of specific types of equipment. Therefore, this cost refers to the upfront cost incremental cost related to building energy performance enhancement in relevant BEE compliance scenarios.

UFC=Initial cost without BEE standard – Initial cost with BEE standard

(5.2)

In this calculation, UFC is the estimate from panel data regression. Estimation of up-front cost is based on the province-level data from China fixed asset investment year book (2001-2008) and modified by model 1 in section 4. The results show that the average upfront cost is 9.2 percent of the total building construction cost for 50 percent energy saving BEE and 19.4 percent of the total building construction cost for 65 percent energy saving BEE. Additional costs related to BEE improvement relative costs described above are accounted for on the per unit floor area basis.

5.2 Benefit of energy saving

The main reason to introduce BEE standards is to reduce the energy consumption of building sector. Currently, Chinese residential building sector consumes approximately 20 percent of the country's final energy. Local BEE standards that set the targets that reduce the energy consumption in heating, cooling and lighting by 50 percent or 65 percent is based on the building energy consumption performance of 1980 level.

$$BE_i = C_e \Delta \sum (E_{heating} + E_{cooling} + E_{lighting}), \quad (5.3)$$

where BE_i is benefit of energy saving relative to BEE standard i; C_e stands for the cost of energy producing; and $\Delta\sum(E_{heating}+E_{cooling}+E_{lighting})$ represents the energy saving in heating, cooling and lighting.

In China, heating is delivered primarily by central or district heating plants fuelled predominantly by coal. Space heating and water heating together are account for nearly 60 percent of energy consumption in residential buildings in north China. In 1986, China's central government issued its first BEE standard, "Energy Design Code for Heated Residential Buildings" (JGJ 26-86). In JGJ26-86, China central government set the quota of each province's coal needed per square meter for heating and set these number as the baseline energy consumption performance. However, as I discussed in the section 2, China's central heating supply systems are one-pipe heating system that cannot be controlled by individual apartments or buildings. For this reason and lag in technology overheating is prevalent. According to the China building energy efficiency annual report (2009), the actual coal consumption for heating is 25% more than required.

As I discussed in the section 2, cooling is not provided centrally in Northern China. During the summer months, when average temperatures are between 25 and 30 ℃, air conditioners are increasingly being used. Electricity costs for cooling with air conditioners are paid directly by the households according to the consumption. Nevertheless, because of the climate, air condition is used much less in Northern China as compared to Southern China. Some provinces, such as Gansu, Qinghai air conditioners are seldom used for cooling. Energy consumption for lighting did not change much before and after BEE standard improvement in residential building sectors. Estimations of the energy consumption for cooling and lighting are based on China building energy efficiency report (2008).

In the NPV calculation, the costs of energy producing include the cost of heating and electricity production. In China, the price of coal for heating is determined by the market, however, the price of electricity is controlled by the government. Therefore, the market price does not necessarily reflect the real social cost of consuming the natural resources, particularly in cases where energy use is heavily subsidized by the government. Although, it is often difficult to value this social cost in practice, we use the market price as a proxy of resource consumption cost. It is foreseeable that domestic energy price in China and international benchmark prices will be converging in the long run. According to the state electricity regulatory commission of China, in 2008, the average cost of electricity transformation from coal is 0.557 yuan per kg. The price of central heating in each province is given in section 2.

5.3 Benefit of carbon emission abatement

Before the United Nations Climate Change Conference Copenhagen, China announced that by 2020 it would reduce its carbon emissions intensity by 40 to 45 percent compared with 2005. China claimed that this target would be "a binding goal" incorporated into China's medium and long-term national social and economic development plans (China’s state council, 2009). Enforcement and implementation of BEE standard can significantly contribute to carbon emissions reduction in buildings. Improved BEE can lead to significant reduction in electricity consumption of space heating and cooling. I approximate the flow of carbon benefits by:

$$BC_i = P_c \cdot Carbon\ emission\ abatement, \tag{5.4}$$

where BC_i is benefit of carbon emission abatement relative to the BEE standard i; P_c is the price of carbon emission. I assume the carbon price is fixed over time.

A range of the carbon emission price from 0 to 250 USD per ton is analyzed. The exchange rate of US$/CHY is 6.82 in 2008. The carbon emission abatement can be deduced from coal consumption. According to National Development and Reform Commission, it can reduce 2.62 kg carbon emission by saving 1 kg coal.

5.4 Discount rate

The discount rate converts future values of benefits into current values so that they may be balanced with up-front costs of building construction. I consider a range of discount rates, in part because the socially correct rate of discount is uncertain, and in part because the trend in benefits is uncertain, as described above. A third factor affecting the discount rate is the risk premium that should be applied to uncertainty about the flow of benefits. In the Capital Asset Pricing Model (CAPM) or any of its modern variants, the risk premium associated with any investment is determined by the covariance of expected returns with the aggregate economy. In this case, the flow of energy-saving benefits is tied to the price of coal: the higher are energy prices, the greater the flow of energy savings benefits. Thus, the risk premium depends on the covariance of uncertain coal prices with uncertain growth in the Chinese economy. If unexpectedly high coal prices cause unexpectedly slow growth in the Chinese economy, then the risk premium would be negative. That is, investments in energy conservation would provide some insurance against the possibility of high future coal prices. This would reduce the discount rate below low-risk interest rates. Alternatively, if unexpectedly high oil prices are expected to follow from unexpectedly high growth, then the risk premium and appropriate discount rate would be higher.

Because expected trends and fluctuations in coal prices are critical for the appropriate discount rate, here I provide some background information on recent coal prices.

China’s central government reformed the coal market and price system in 1993, before which the price of coal was controlled by the government. This reform made coal prices subject to market forces of global demand and supply. Coal prices decreased after 1997 and reached a low point in 1999, after which time coal prices began to increase. Demand for energy increased sharply because of the rapid economic growth after 2001. Since coal accounts for the largest share of China’s energy, this growth comprised a significant share of global growth in coal demand. Coal prices kept rising after 2004 and reached their highest point in 2008, the year when China was hit by a big storm and commodity prices spiked worldwide. Figure 6 show the trend of coal price (Resource: China Coal Resource, BP company).

Figure 6 Coal Price Trend

The increasing trend of China's coal prices can be explained by a number of factors. First, price system reform made coal prices subject to market forces of demand and supply relationships instead of government control. Secondly, China's rapid growth increased the demand for energy; however the ability of coal supply to respond to demand was underdeveloped. Furthermore, the nature of China's heating centralized heating system in which payments for heating energy are tied to living area rather than energy consumption makes demand inelastic. Third, China's coal reserve is mainly located in the western and northern areas, while the biggest demand for coal comes from the eastern and southern parts of China, which makes the coal transport expensive. Fourth, in recent years, China's government began to impose some environmental, resource and security fees on coal industry, which increased the cost of coal production. Fifth, China became a net importer of coal in 2009. That means the international coal price began to affect China's coal price.

While prices have been trending up, it is difficult to tell whether that trend will continue. But even a modestly increasing trend in prices would justify a very low discount rate. The covariance between energy prices and economic growth is equally difficult to discern. In past decades there has been documented evidence that positive spikes in energy prices have lead to recessions or reduced economic growth, which would indicate a lower discount rate. In this study, I pick 1 percent as the relative low discount rate. More recently, however, it appears price fluctuations have been demand related, would suggest a higher discount rate (Kilian, 2009). If the increasing of coal price is caused by unexpectedly high growth in China, it is better to choose a higher discount rate. In this study, I use the 8 percent as the relatively high discount rate. I also calculate the NPV under the discount rate equals 5 percent as the result in middle of the two.

5.5 Results

Improving BEE standard allows for significant reductions both in primary energy consumption and associated carbon emissions. Implementation of the 50 percent energy saving BEE standard in new construction buildings increase the construction cost and implementation of 65 percent energy saving BEE standard save more energy; however, on the other hand, the stricter standard costs more. Take Beijing as an example. Figure 7 reports the Net Present Value of investment on BEE improvements for Beijing.

For Beijing, assuming the discount rate equals to 1 percent, the net present value of implementing the 50 percent energy saving BEE standard is 407.77 yuan per square meter when the carbon emission price is zero. Because the NPV is positive, the investment on 50 percent energy saving BEE standard is acceptable. The NPV increase when carbon emission price goes higher, which indicates the benefit of investment on BEE improvement has a positive linear relationship with the carbon emission price. On the other hand, the NPV of investment on 65 percent energy saving is 319.99 yuan at zero point, which is lower than 50 percent BEE. Therefore, the 50 percent BEE standard will be more beneficial when the value carbon emission reductions are zero. The NPV of 65 percent BEE is more sensitive to the carbon emission price; that is, it increases more sharply than that of 50 percent BEE when the carbon emission price goes higher. NPV of 50 percent BEE and 65 percent BEE equal at the point when carbon emission price is 28 USD per ton. For carbon prices above $28 per ton, the NPV of investment on 65 percent BEE standard exceeds that of the 50 percent BEE standard. This suggests that if the carbon emission price is higher than 28 USD per ton, invest on 65 percent BEE standard will gain more benefit than invest on 50 percent BEE standard.

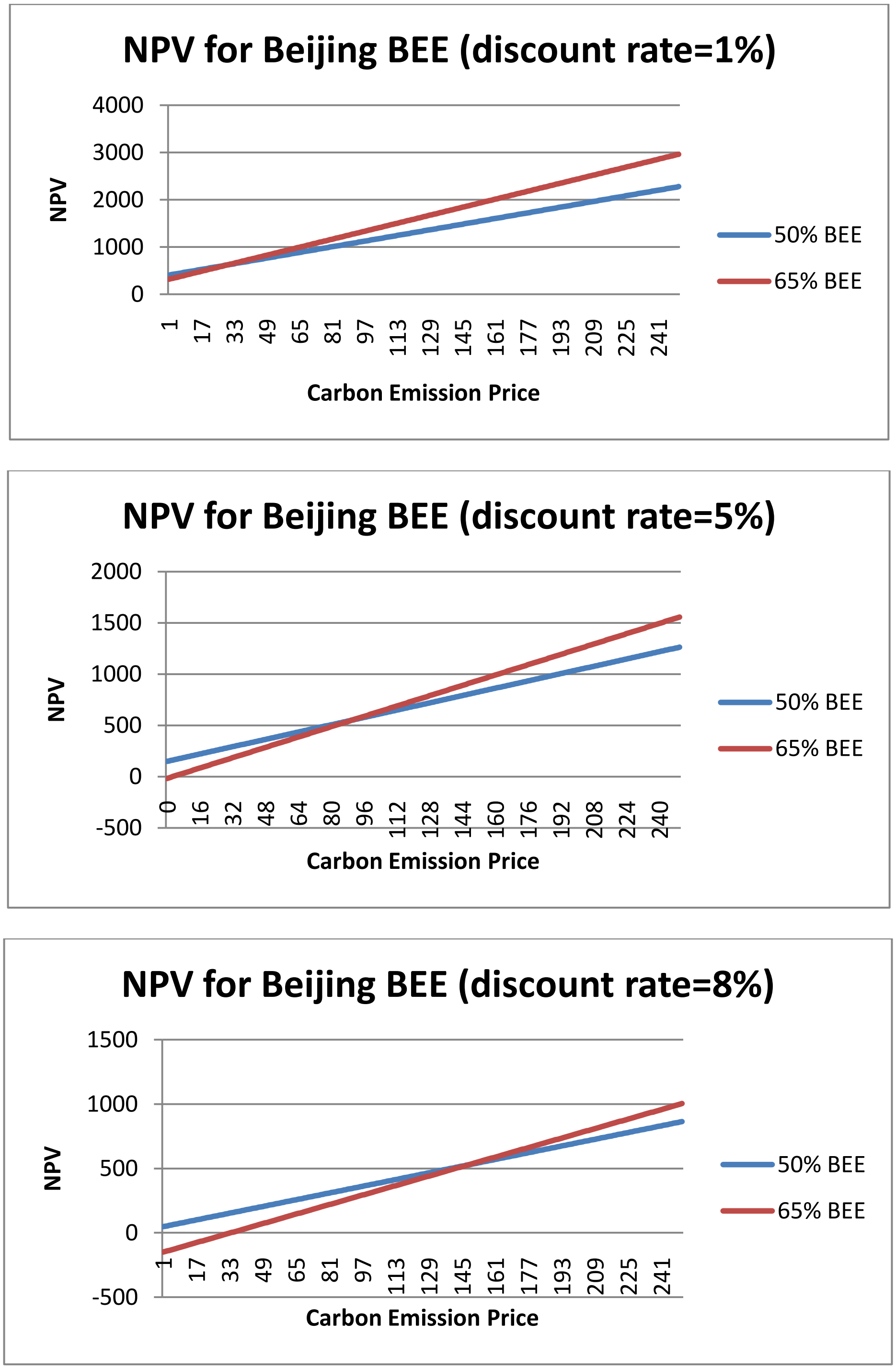

Figure 7 Net present value of investment on BEE improvement for Beijing

The NPV is lower when discount rate is 5 percent compared with 1 percent at the same carbon emission price. Assuming the discount rate equals to 5 percent, NPV of investment on 50 percent BEE standard is 149.81 when carbon emission is free to emit. It is still positive and the NPV goes higher with the increase of carbon emission price, which indicates the investment on 50 percent energy saving BEE is acceptable. However, on the other hand, NPV of investment on 65 percent BEE standard is -17.07 when the discount rate is 5 percent at the point of carbon emission price is zero. NPV of 65 percent BEE will be negative at the zero point until the carbon emission price exceeds 5 USD per ton, which suggests the investment on 65 percent energy saving BEE costs more than its gains when carbon emission price is less than 5 USD per ton. NPV of 50 percent BEE and NPV of 65 percent BEE will be equal when carbon emission price is 90 USD per ton. It means if the carbon emission exceeds 90 USD per ton 65 percent energy saving BEE standard is the better investment compare with 50 percent energy saving BEE standard.

The NPV results related to the high discount rate which equals to 8 percent in this study showed in the third figure. The NPV of investment on 50 percent energy saving BEE standard and 65 percent energy saving BEE standard are 48.09 yuan and -149.97 yuan respectively when carbon emission price is zero. The NPV of 50 percent BEE and 65 percent BEE will be equal at the point where carbon emission price is 147 USD per ton.

Results for rest of the provinces are reported in the appendix. From our NPV estimates for 15 provinces in North China, results show:

1. All of these 15 provinces have positive NPV for investment on 50 percent energy saving BEE standard when carbon emission is free under certain discount rate (1%, 5%, 8%). It implies investment on 50 energy saving BEE standard is acceptable for provinces in North China.

2. However, 50% energy saving is not always the best option for all province when carbon emission is free. At low discount rate scenario (1%), provinces, such as Jilin, Liaoning and Gansu, investment on 65 percent BEE standard have a higher NPV at the zero point. That indicates the optimal BEE option varies across provinces under same discount rate and carbon emission price.

3. NPV of investment on BEE has a positive relationship with the price of carbon emission and the growth rate for 65 percent BEE energy saving standard is higher than 50 percent energy saving standard. It suggests when carbon emission price exceeds certain number the optimal BEE standard will change from 50 percent energy saving BEE standard to 65 percent energy saving BEE standard for some provinces.

6 Carbon Emission Abatement Curve

Based on the results of our NPV analysis, we realize that the optimal BEE standard varies across provinces under the same specification. And for each province, the optimal BEE standard depends on the discount rate and carbon emission price. Therefore, the amount of carbon emission abatement contributed by BEE standard improvement is associated with the carbon emission price and discount rate. In this section, I examine the carbon emission abatement potential related to the BEE improvement and how it changes with the carbon emission price. I project a growth curve of each province optimal BEE standard and its abatement efficiency. To be specific, I examine new construction buildings in 2008 and estimate the change of carbon emission potential with the increase of carbon emission price under each discount rate.

The construction area data are collected from China fixed asset statistical year book and I choose the year of 2008 because that is the latest official statistics. I assume each province will choose its optimal BEE standard, which is associated with the highest NPV under certain carbon emission price and discount rate. That is, for example, if current carbon emission price 30 USD per ton and the discount rate is 5 percent, the optimal BEE standard for Beijing in 2008 is 50 percent energy saving BEE. However, if the carbon emission increases to 100 USD, then the optimal BEE standard for Beijing in 2008 change to 65 percent energy saving BEE standard. The optimal BEE standard selection is based on the NPV analysis in section 5.

The carbon emission potential is calculated from the carbon emission abatement per square meter and the total area under construction for each province. I extend the carbon emission price range to include values negative enough such that no BEE standard is optimal, up to positive $100 per ton of CO_2. I then estimate the prices at which the optimal BEE standard will change from doing nothing to implement 50 percent energy saving standard for each province. Thereafter, I estimate the prices at which the optimal BEE standard will change from implement 50 percent energy saving BEE standard to 65 percent energy saving BEE standard. Figure 8 shows carbon emission abatement curve when the discount rate is set equal to 5 percent.

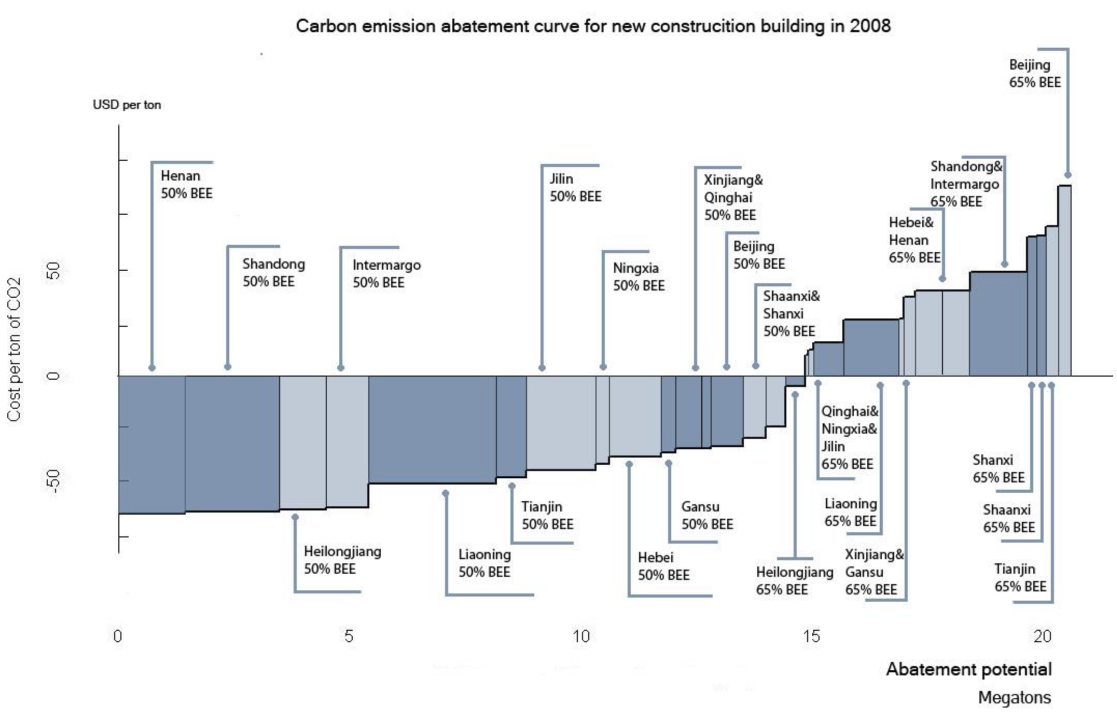

Figure 8 Carbon abatement curve for new construction building in 2008 (discount rate=5%)

Henan province has the lowest abatement cost. From figure 8, we can see when carbon emission price exceeds -66 USD per ton the optimal BEE standard for Henan is change from doing nothing to implement 50 percent BEE standard. Consider the efficiency of carbon emission abatement per square and the total under construction area in 2008, implementation of 50 percent BEE standard will reduce 1.44 megatons per year carbon emission in Henan province. Shandong, followed Henan, will switch its optimal BEE standard to 50 percent BEE at the price of -65 USD and by implementing 50 percent BEE New construction building in Shandong will reduce 2.05 megatons per year carbon emission. Shanxi province has the highest abatement cost, where will not implement any BEE standard until carbon emission price exceeds -24 USD. In realistic, carbon emission price is non-negative, hence, we can say every province can reduce its carbon emission at low even negative price by improving BEE standard.

In addition, back to Henan province, it will switch its BEE standard to 65 percent BEE when carbon emission price exceeds 41 USD and this change will reduce additional 0.58 megatons carbon emission per year at the base of 50 percent BEE implementation. Therefore, the carbon emission abatement potential for new construction building in 2008 in Henan province is 2.02 megatons per year. For single province, Liaoning province has the biggest carbon emission abatement potential, which equals 3.95 megatons per year as long as carbon emission price exceeds 26 USD. Shandong has the second biggest carbon abatement potential which is 2.91 megatons per year. When carbon emission price is higher than 90

USD, all of 15 provinces will choose 65 percent BEE and under that situation the total carbon emission potential of new construction in 2008 is 20.61 megatons per year.

Currently China has not price the carbon emission yet. Therefore, I suppose the carbon emission is zero. Based on the optimal choice rule (implement the BEE that has the highest NPV), we can conclude that 14 province implement 50 percent BEE and the other one (Heilongjiang) choose the 65 percent BEE, the total carbon emission abatement potential of new construction buildings in 2008 in these provinces is 14.85 megatons per year.

When the discount rate change to low discount rate which equals to 1 percent or high discount rate which equals to 8 percent, the results are showed in Figure 9 and Figure 10.

Figure 9 Carbon emission abatement curve (discount rate = 1%)

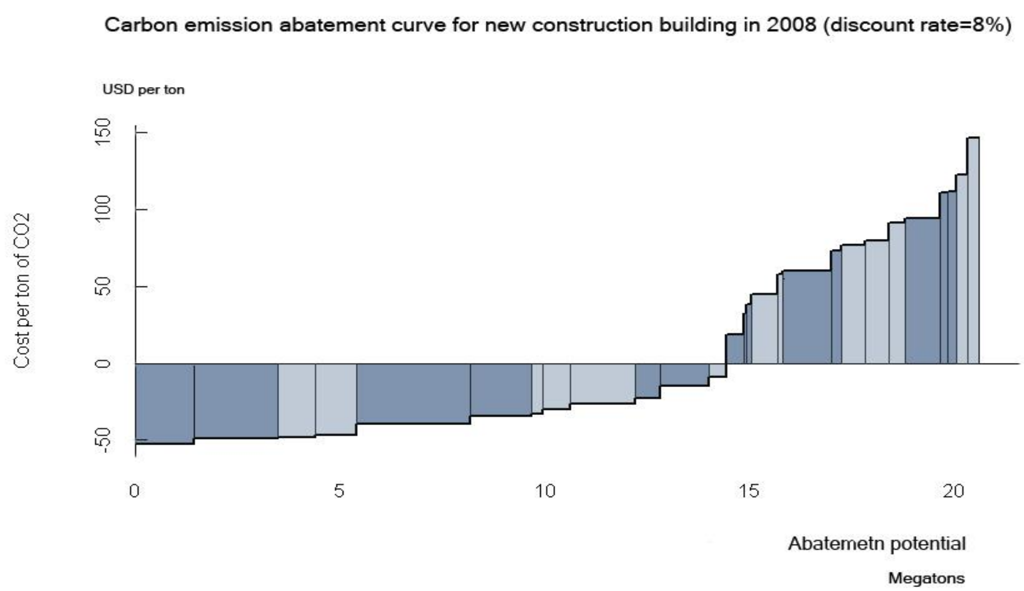

Figure 10 Carbon emission abatement curve (discount rate = 8%)

The abatement cost varies with discount rate. Compared with carbon emission abatement curve at 5 percent discount rate, abatement potential will be larger at the same carbon emission price when discount rate changes to 1 percent. Put it in another way, each province has low abatement cost when discount rate is relative lower. In contrast, new construction buildings have smaller abatement potential at the same carbon emission price when discount when discount rate is 8 percent. That is carbon abatement cost more when discount rate is relative higher.

I am not aware of any existing study that analyzes the NPV of China BEE improvement and evaluates the effect of BEE standard on carbon emission abatement. In 2006, Mckinsey published a report on China carbon emission abatement potential, in which Mckinsey curve for China carbon emission abatement was introduced. Mckinsey curve is a cost curve for carbon emission reduction that describes the carbon emission abatement potential and relative cost. Our abatement curve use the familiar way to present our results. The difference between Mckinsey curve and ours are:

1. Mckinsey curve is a universal report that contains policy, technology and behavior for the whole nation. On the other hand, our curve focuses on the BEE improvement part and considers the regional effect. We consider the discount rate, carbon emission price and analyze the NPV of investment on 2 types of BEE improvements for each province and calculation the carbon abatement potential separately.
2. The building construction cost data that used to describe the incremental cost relative to BEE improvement in Mckinsey's study is collected from real cases study.

And the estimates of the energy consumption in Mckinsey's report are average numbers for the whole nation. For example, Mckinsey estimates the coal consumption for heating per square meter will be 16 kg in 2030 and the incremental cost related to BEE improvement for north part of China will be 9 EUR per square meter. On the other hand, our study based on the province level data, gives the estimates for each province separately.

7 Conclusion

In response to the energy security and climate change, China central government improves its national BEE standard in order to reduce the energy intensity of GDP and carbon emission intensity of GDP. In 2005, China central government set BEE target in its 11th Five-Year plan, which required newly construction buildings at least achieve 50 percent energy efficiency compared with the 1980s building energy consumption performance. In the following years, vast majority of provinces have improved their local BEE standards and forced newly construction buildings to comply with. Despite widespread implementation of new BEE standard, surprisingly little is known about how the BEE improvement effect the building construction cost in practice, what is the optimal BEE standard for different region and how BEE improvement effect carbon emission abatement.

The primary contribution of this paper is the evaluation of NPV of investment on BEE improvements for 15 provinces located in north part of China. Using the province-level construction cost data, energy performance data, we find investment on 50 percent energy saving BEE standard and 65 percent energy saving BEE standard will increase the construction cost by 9.2 percent and 19.4 percent respectively. And the NPV of investment on BEE improvement for each province depend on carbon emission price and discount rate. We draw the trend of NPV change with the carbon emission price under certain discount rate, which can provide information for the optimal BEE standard for each province under certain specific.

Based on our NPV analysis, we find the investment on 50 percent energy saving BEE standard is acceptable, considering current carbon emission is free to emit in China. While, if carbon emission begin to price and the price exceeds some certain number, 65 percent energy saving BEE is a better option. We also project a carbon emission abatement curve, which draw the relationship between carbon emission price and carbon emission abatement potential related to BEE improvement. From the abatement curve, we conclude that provinces in north part of China can reduce their carbon emission at low or negative cost.

My estimates are based on three of China's unique conditions: heating service is charged by area, carbon emission is free to emit and electricity prices are controlled by the government. 2010 is the last year in 11^{th} Five-Year Plan, though BEE improvement from 2005 to 2010 contribute significantly in energy efficiency and carbon emission reduction, China still has great potential to improve its energy efficiency performance in building sector. China will release its 12^{th} Five-Year Plan in 2011, so we are going to project some changes in its energy policy and discuss their effects. Firstly, if China change to charge heating service by actually use instead of heating area, household can control the heating use and they will have an incentive to save energy. As a result, consumers will prefer to live in the energy efficiency buildings considering the energy bill, which is also an incentive to improve BEE standard. However, that would bring a new problem-who should invest on BEE improvement, the consumer or the develop companies? Because currently heating is charged by area, consumers do not have any incentive to choose the energy efficiency building if it is more expensive. Therefore the develop companies are difficult to pass the increment cost to consumer. While, if China reforms its heating service system, the burden of investment on BEE would be relocated. Second, if China put a price on carbon emission, which is free to emit so far, it is also an incentive to improve the BEE standard. Based on our estimations, with the increase of carbon emission price, the 65 percent energy saving BEE is more likely to be chosen. Third, if China government open the electricity industry and let the electricity price determined by market, the electricity price will go with the change of energy price. Considering the trend of China's energy price, the electricity price would be higher compared with that under government control. That is also an incentive for consumers to choose living in the energy efficiency buildings. Such policies, like heating system reform, priced on carbon emission and electricity price system reform will be helpful to improve energy efficiency and reduce carbon emission. However it may relocate the burden of investment on BEE improvement and push the housing prices higher, which is already un-affordable for many citizens. How to balance these issues will affect China's future development. We will pay attention to 12th Five-Year Plan, see whether China will make some change in its energy policy and do some future study.

The biggest limitation of this paper is the data resource. The best data that I can reach is the province-level data. I know little about how the survey be conducted and what problem there may exist. Therefore, if there are some problems in the way of data collection, the estimates in this thesis may be biased. Access micro-level or raw data would facilitate more detailed and comprehensive analysis.

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Appendices

Appendix A: Research Area

Figure 11 Central Heating Regions

Figure 12 Climate Regions

Figure 13 GDP Level

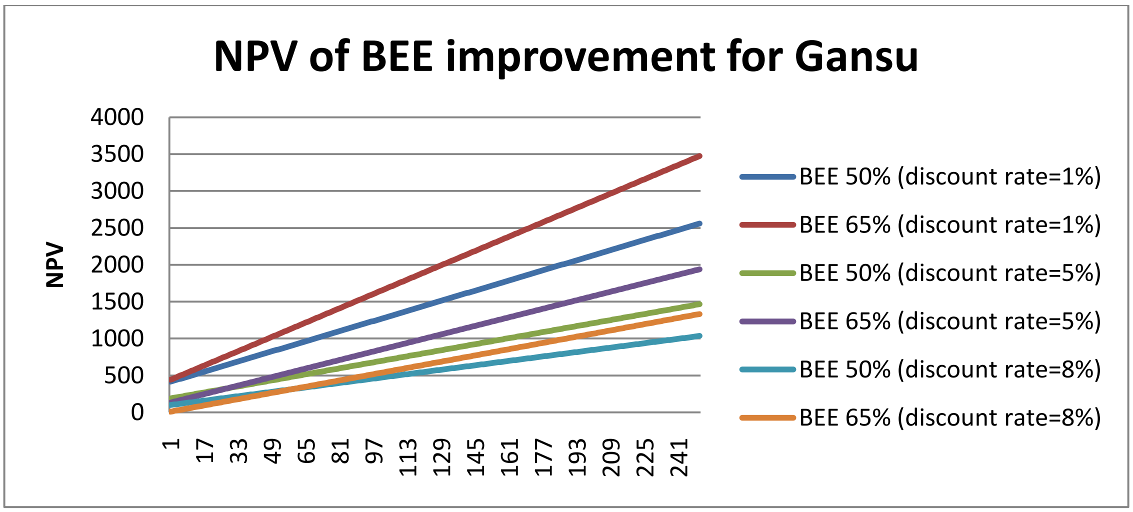
Appendix B: Effect estimates

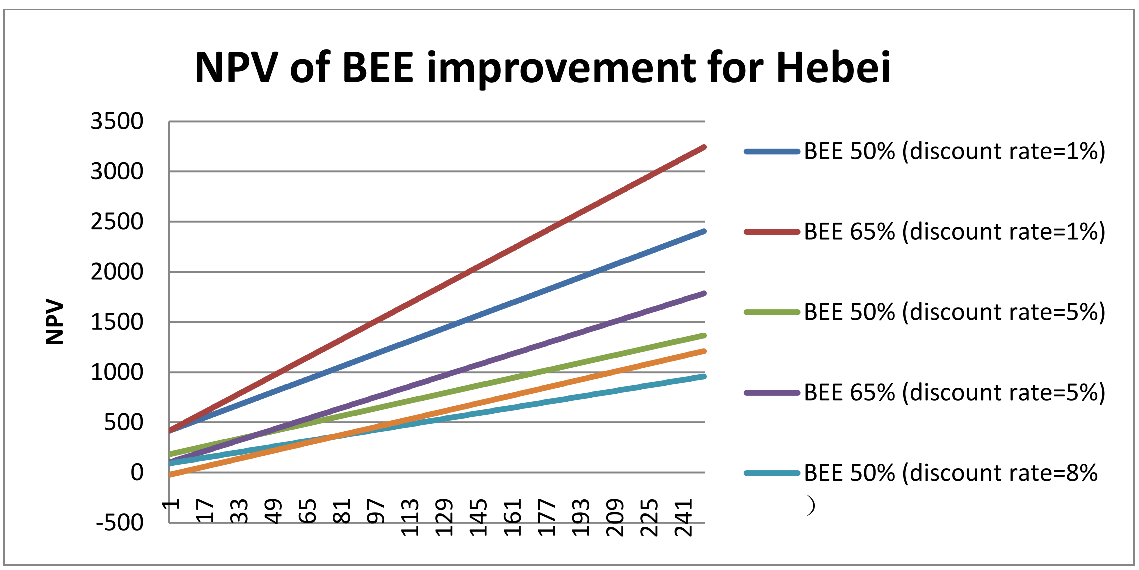
Model Depend variable	(1) Log of Cost	(2) Real Cost
Province		
Beijing	3.50 （0.023）	2711.26 (76.13)
Tianjin	3.45 （0.027）	2571.69 (90.33)
Gansu	3.30 （0.032）	2067.95 (105.92)
Hebei	3.35 （0.032）	2208.57 (105.92)
Heilongjiang	3.33 （0.034）	2166.54 (114.1)
Henan	3.24 （0.033）	1963.74 (109.9)
Intermargo	3.28 （0.032）	2023.07 (105.9)
Jilin	3.38 （0.037）	2273.88 (123.08)
Liaoning	3.36 （0.034）	2239.79 (114.1)
Ningxia	3.25 （0.033）	1976.49 (109.9)
Qinghai	3.33 （0.032）	2149.82 (105.9)
Shaanxi	3.39 （0.033）	2326.99 (109.9)
Shandong	3.34 （0.031）	2158.37 (104.3)
Shanxi	3.35 （0.033）	2225.37 (109.9)
Xinjiang	3.36 （0.037）	2235.88 (123.08)
Year		
2001	-0.10 （0.021）	-231.84 (68.45)
2002	-0.087 （0.021）	-205.17 (68.45)
2003	-0.056 （0.021）	-140.1 (68.45)
2004	-0.036 （0.021）	-89.1 (68.45)
2005	-0.017 （0.018）	-32.03 (59)
2006	-0.032 （0.016）	-94.88 (51.59)
2007	-0.03 （0.015）	-83.93 (51.02)

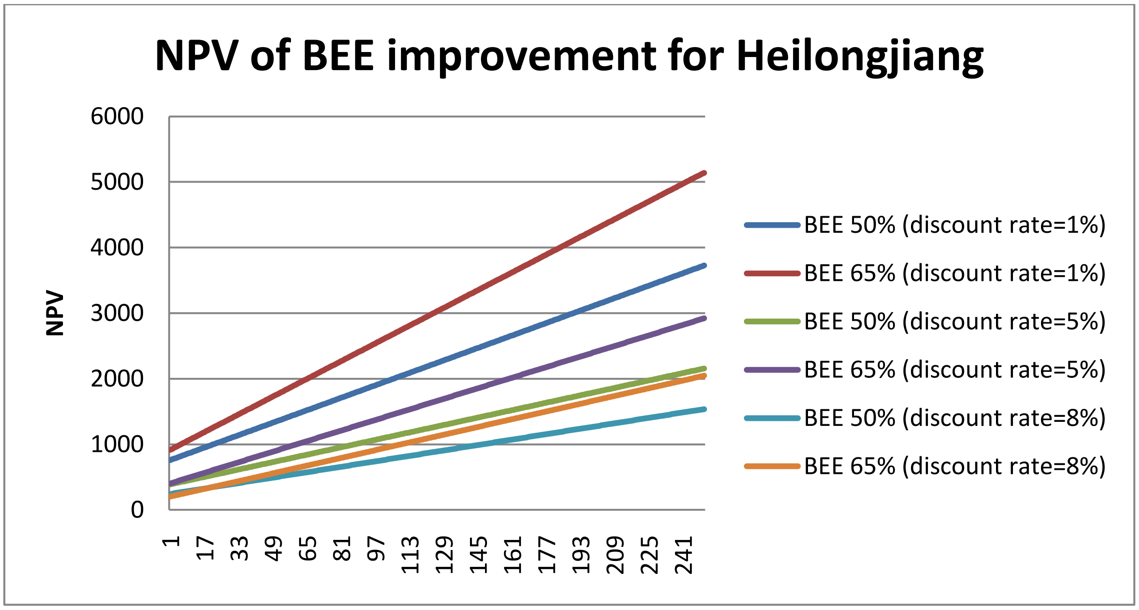
Note: (1) refer to Model 1 in section 4 and (2) refer to Model 2 in section 4 (page 21). The money term for real cost is China's yuan. In 2008, 6.82 yuan equals to 1 USD.

Appendix C: Analysis of NPV of BEE improvement

NOTE: Each graph represents the estimates of NPV of two types BEE improvements (50% energy saving BEE standard and 65% energy saving BEE standard) for each province under certain discount rate (1%, 5%, 8%). From each graph we can see that the NPV increases as the carbon emission price increases.







NPV of BEE improvement for Heilongjiang
NPV
6000
5000
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161
177
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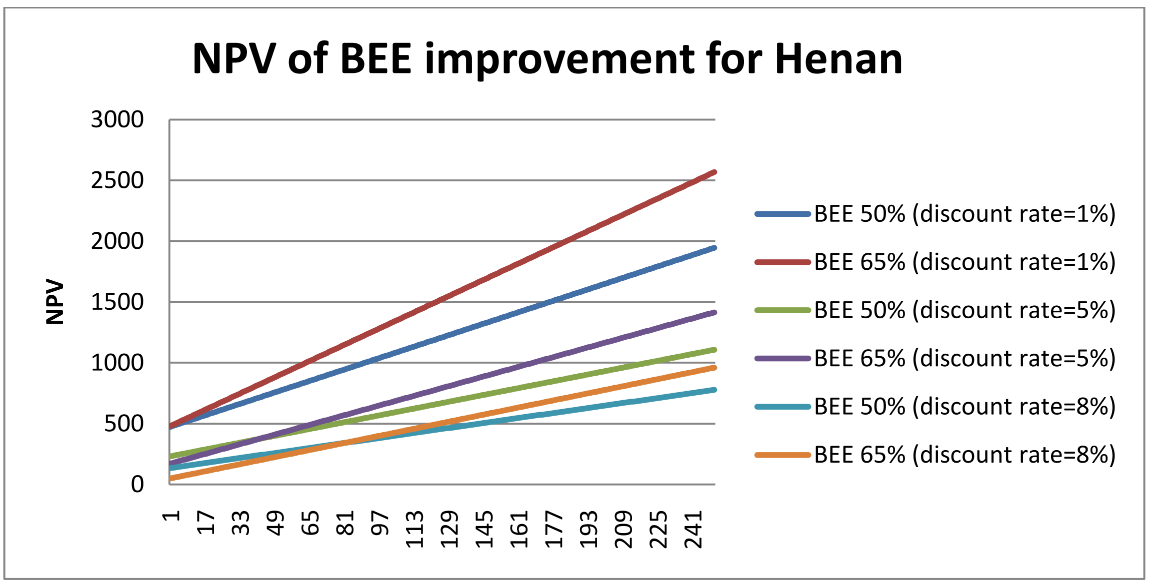
225
241
BEE 50% (discount rate=1%)
BEE 65% (discount rate=1%)
BEE 50% (discount rate=5%)
BEE 65% (discount rate=5%)
BEE 50% (discount rate=8%)
BEE 65% (discount rate=8%)



NPV of BEE improvement for Henan
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BEE 50% (discount rate=1%)
BEE 65% (discount rate=1%)
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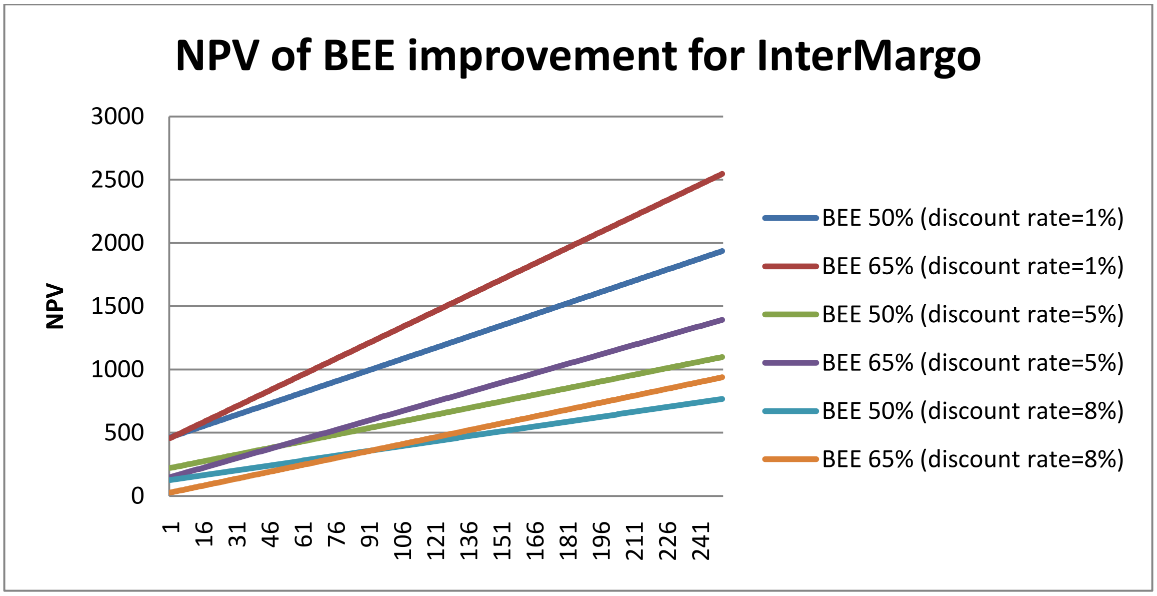
BEE 50% (discount rate=8%)
BEE 65% (discount rate=8%)


NPV of BEE improvement for InterMargo
NPV
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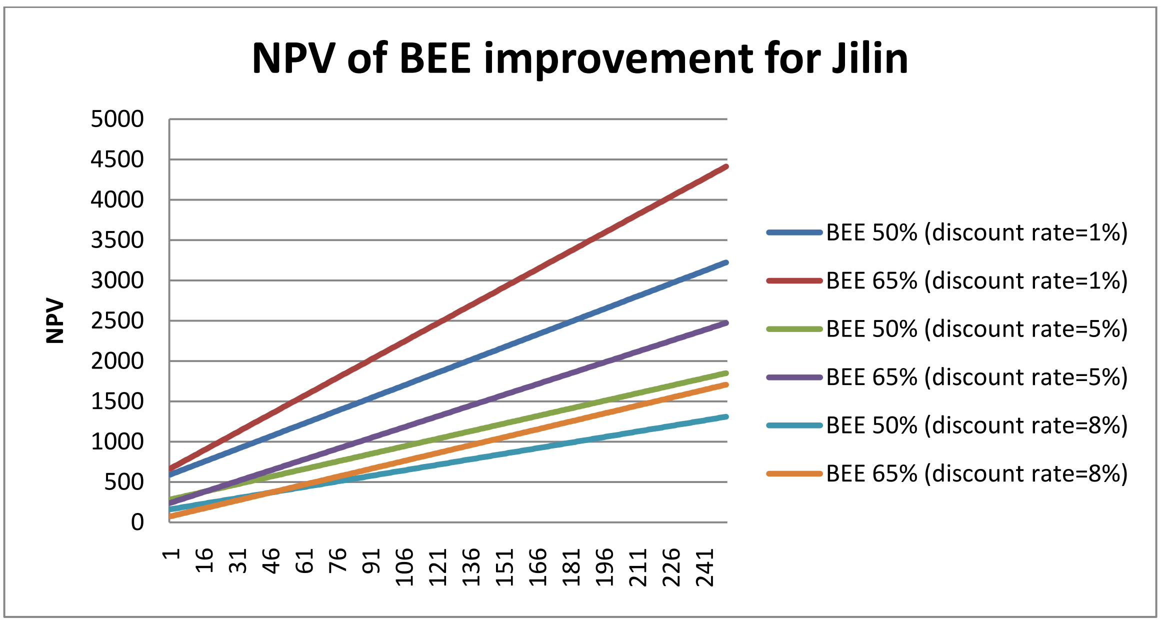
BEE 65% (discount rate=8%)


NPV of BEE improvement for Jilin
NPV
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BEE 50% (discount rate=1%)
BEE 65% (discount rate=1%)
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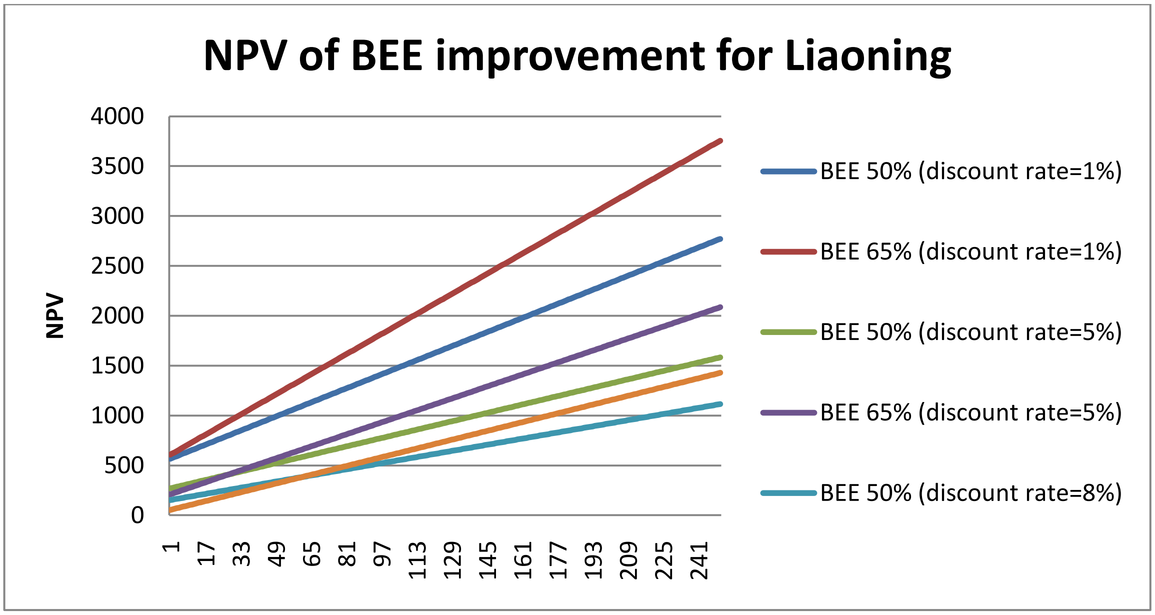
BEE 65% (discount rate=5%)
BEE 50% (discount rate=8%)
BEE 65% (discount rate=8%)


NPV of BEE improvement for Liaoning
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BEE 50% (discount rate=1%)
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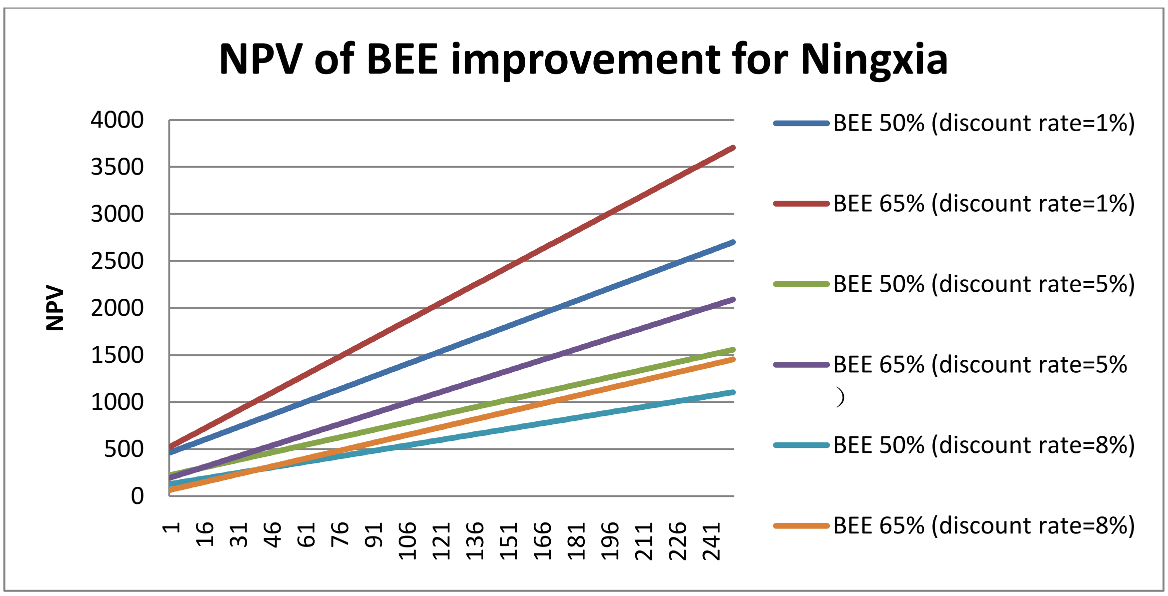
BEE 50% (discount rate=5%)
BEE 65% (discount rate=5%)
BEE 50% (discount rate=8%)


NPV of BEE improvement for Ningxia
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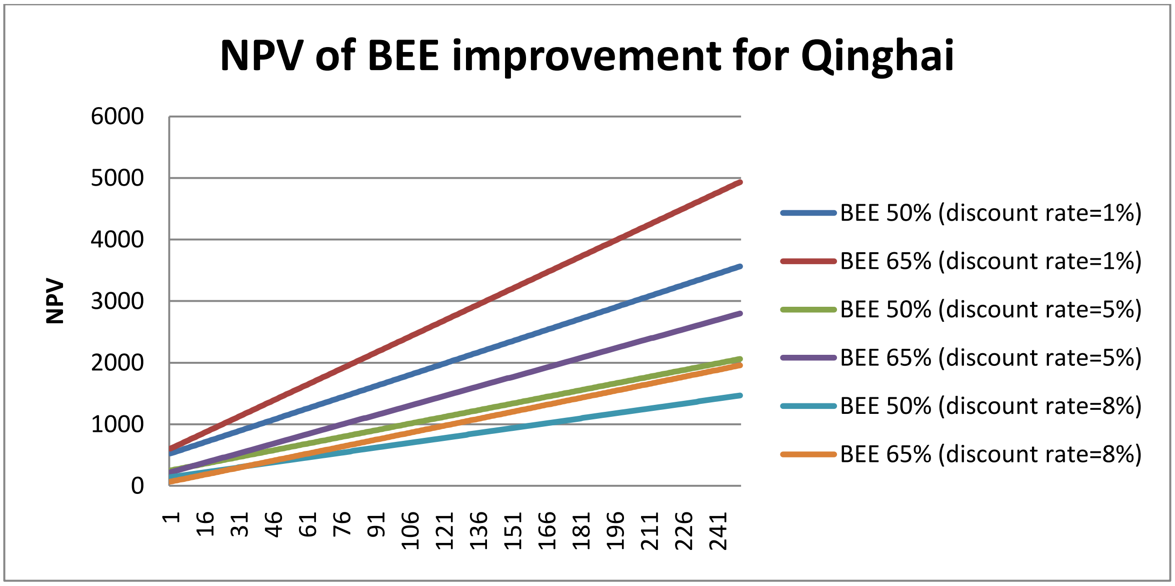
NPV of BEE improvement for Qinghai
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BEE 50% (discount rate=1%)
BEE 65% (discount rate=1%)
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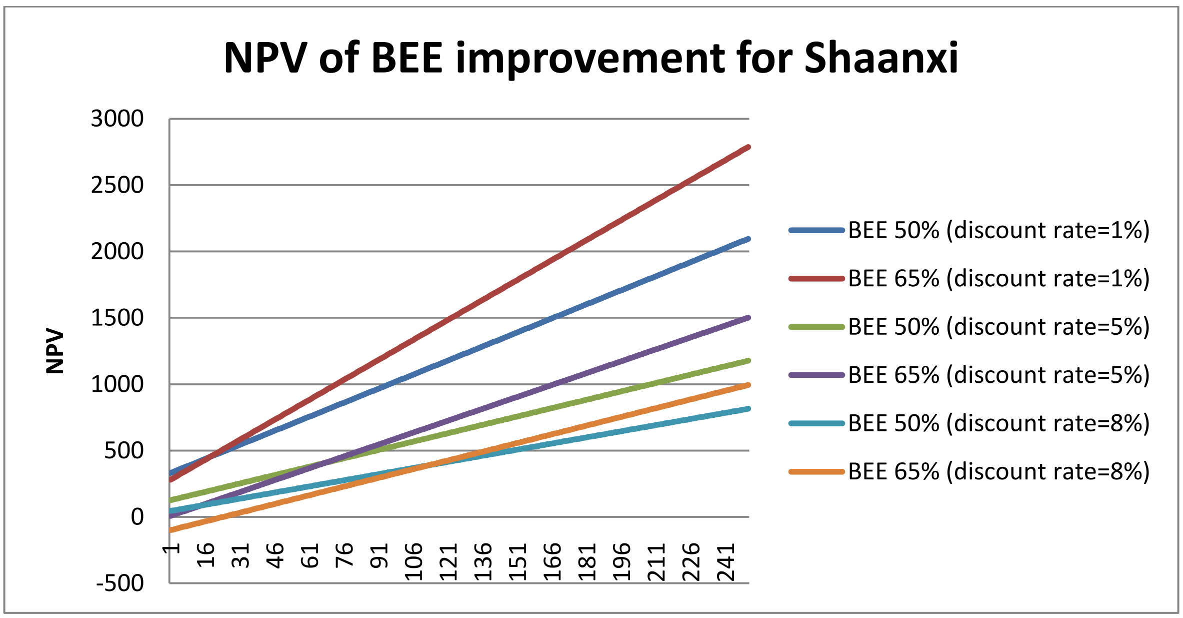
BEE 65% (discount rate=8%)


NPV of BEE improvement for Shaanxi
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BEE 50% (discount rate=1%)
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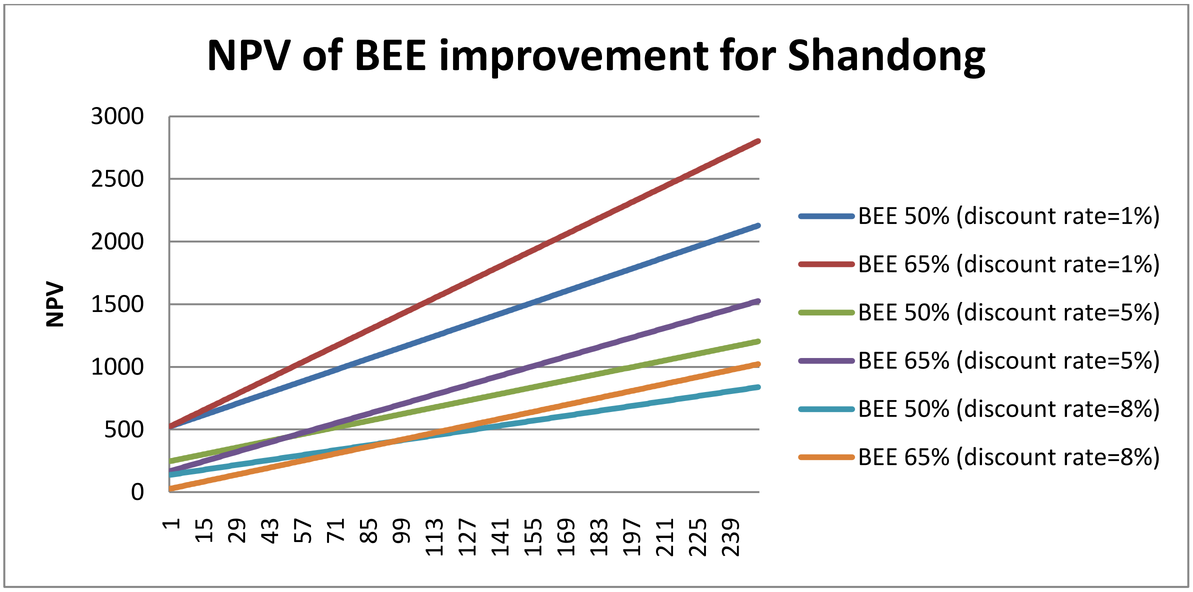
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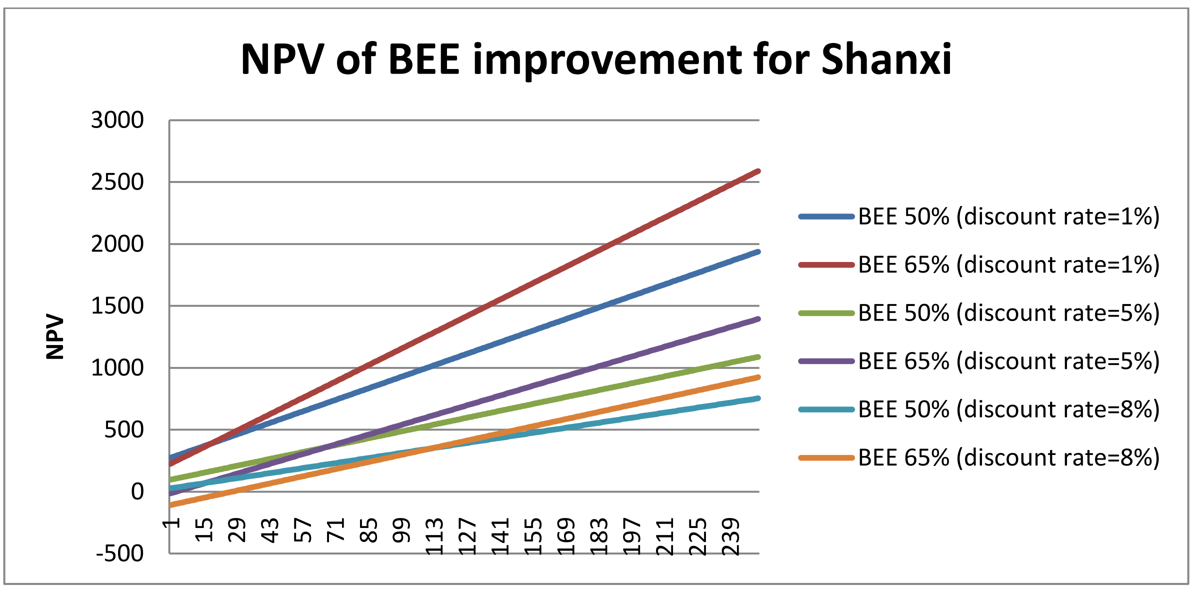
NPV of BEE improvement for Shanxi
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BEE 50% (discount rate=1%)
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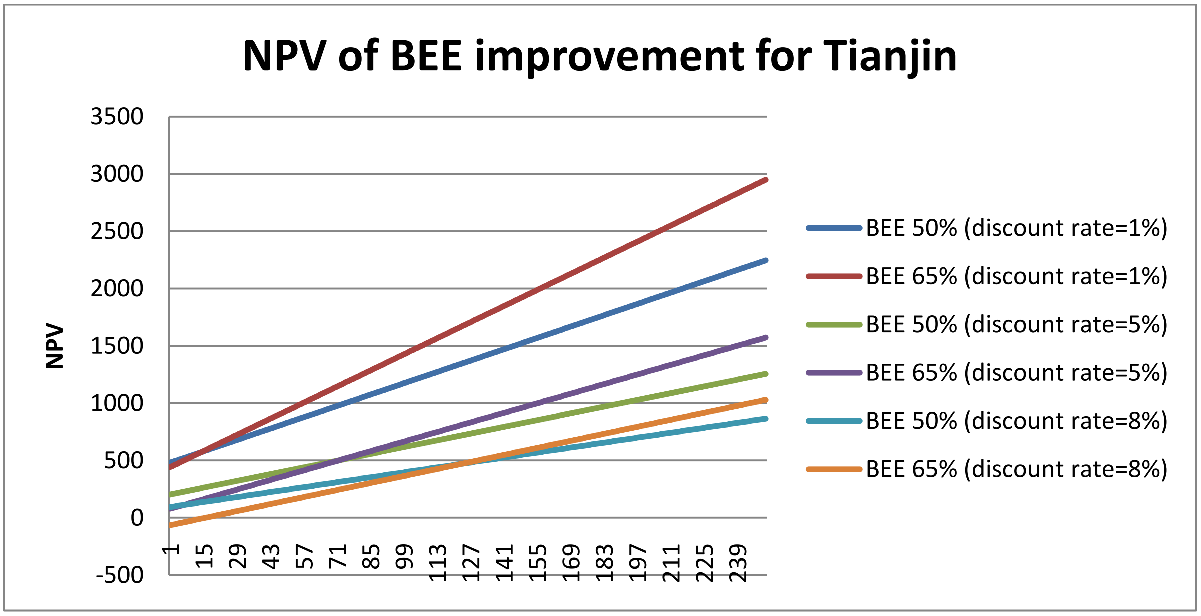
NPV of BEE improvement for Tianjin
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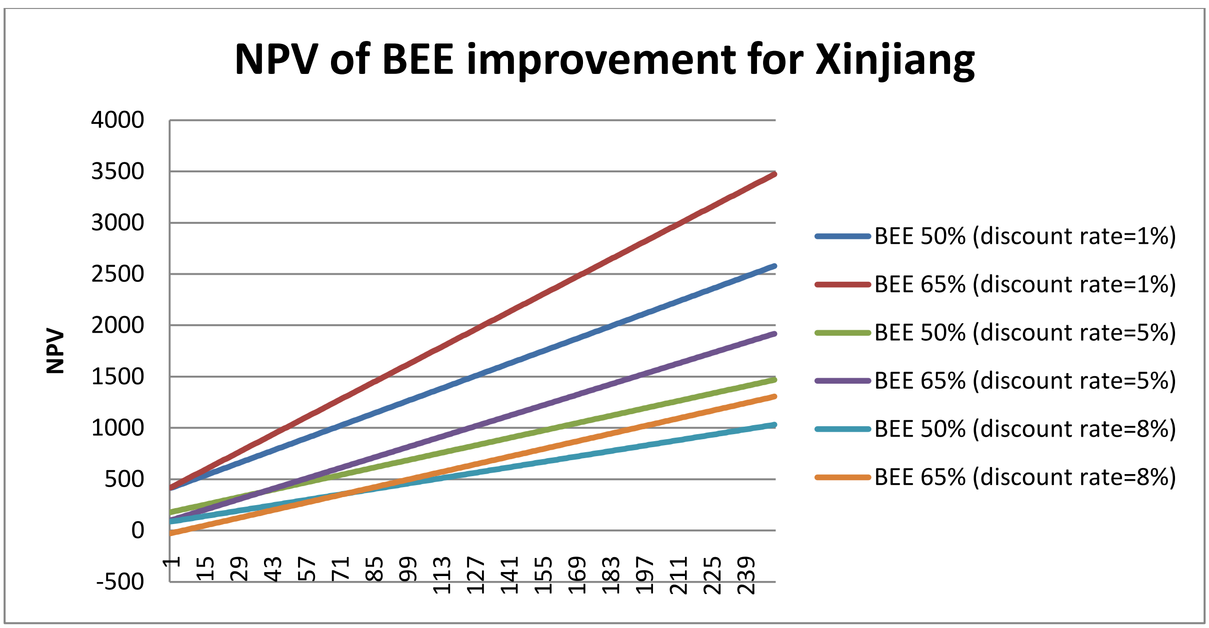
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BEE 50% (discount rate=5%)
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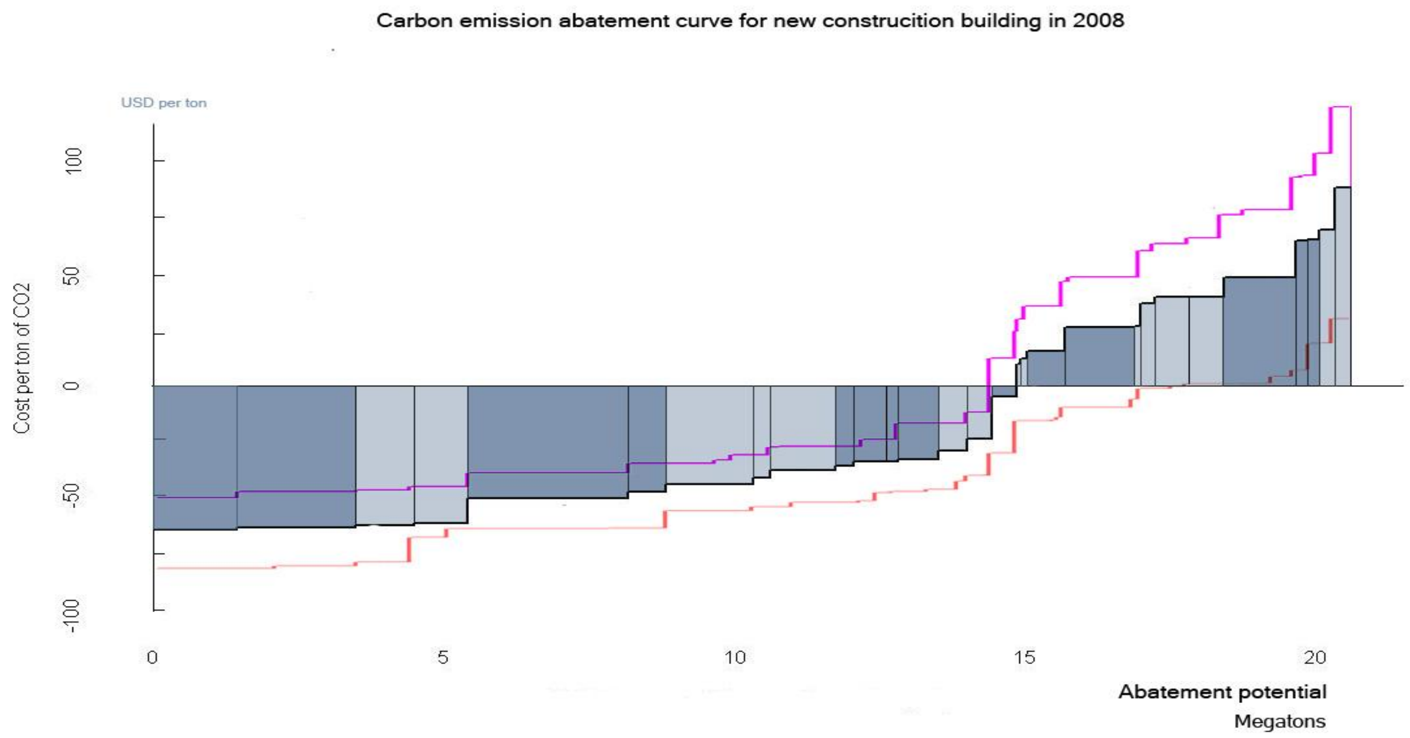
BEE 50% (discount rate=8%)
BEE 65% (discount rate=8%)

Appendix D: Comparison of Carbon Emission Abatement Curves under Different Discount rate



NOTE: This graph represents the joint estimates of the carbon emission abatement curves under certain discount rate (1%, 5%, 8%). The original graph is carbon emission abatement curve when discount rate equals to 5%. The red and violet lines stand for the carbon emission curve when discount rate equals to 1% and 8% respectively.

Appendix E: Residual distribution