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ABSTRACT

China's economic reform over the past 30 years has allowed the free market to drive economic development. However, government still plays a key role in the energy sector by allocating energy conservation and emissions abatement. How does the government make an equity decision as a tradeoff to market efficiency? This is an unanswered question. The purpose of this paper is to illustrate the government's preference toward equity and efficiency. Using the provincial level CO_2 intensity allocation data, we investigate the political decision that the government made based on the equity and efficiency criteria. We find that the equity index plays a more important role than the efficiency index in determining the CO_2 intensity target. In addition, political factors such as social stability are found to be important factors.

Key words: China, Equity, Efficiency, Preference, Policy-maker

1. Introduction

As the largest energy consumer and greenhouse gas (GHG) emitter, China has made substantial effort to mitigate the negative effect of global warming and decouple CO_2 increases from economic growth (Zhang, 2000).[1] During the 11th Five-Year Plan (FYP) from 2006 to 2010, China succeeded in reducing its energy intensity (energy consumption per unit of GDP) by 19.1%. The 12th FYP (2011-2015) established a new set of ambitious targets and aggressive policies to promote low carbon development. The key targets include a 16% reduction in energy intensity from 2010 levels by 2015, and for the first time a 17% reduction in carbon intensity from 2010 levels by 2015 (CO_2 emissions per unit of GDP). The national commitment goal for energy intensity and carbon intensity was further distributed at the provincial level.

The purpose of the paper is to investigate if and in what degree equity and efficiency have been considered by the Chinese government in the provincial burden-sharing scheme. The equity criteria follows the literature "common but differentiated responsibilities" in that every province has the right to use the air but with responsibility (Phylipsen et al., 1998; Baer et al., 2000). This requires an even distribution across provinces while the provinces with greater emissions should assume greater burdens. The efficiency criteria documented under the United Nations Framework Convention on Climate Change (UNFCCC) indicates a cost-effective allocation will be the one at the lowest possible cost (Shukla, 2005). This indicates that the provinces with the lowest abatement costs should take on additional burdens. A tradeoff exists between these two criteria as the provinces with greater emissions should take on greater burdens; however, it leads to less efficiency as the provinces may have higher abatement costs. The final results depend on the

[1] China's self-commitment on energy intensity and carbon intensity has gained much international attention (Qiu, 2009; Stern and Jotzo, 2010; Zhang, 2011) and could serve as an example for the "global problem, local solution".

government preference in weighting equity and efficiency. In addition, the government may have other political factors when considering this allocation decision. To reveal this complicated political decision, we construct equity and efficiency variables following the literature definition. In particular, to construct an efficiency variable, we first derive the shadow price and inefficiency level on the basis of the directional distance function. Based on this, we construct the marginal abatement cost and abatement potential and hypothesize that they will have a significant association to the allocation target should efficiency criteria is considered. An econometric model is specified to identify and examine the determinants of the policy-making process from equity rules, efficiency rules and other political considerations.

The major contribution of this paper is that it is the first one to reveal the political decision based on equity and efficiency in the provincial burden-sharing scheme. There are few papers that put forward an ideal allocation scheme based on efficiency and equity. Yi et al. (2011) presents several burden-sharing scenarios based on different preferences by selecting per capita income, accumulated emissions from fossil-fuel and energy per unit of industrial value-added to represent the CO_2 reduction capacity, responsibility and potential, respectively. Wei et al. (2012) simulate the distribution scheme among provinces using the Slack-based Measure (SBM) approach to establish CO_2 equity and efficiency sub-indexes and weight them into an abatement capacity index for each province. In comparison, this paper adopts a reverse-thinking strategy to deduce the decision making process. Based on the observed scheme from the recent 12th FYP (2011-2015), this paper infers the policy-makers' preference based on equity and efficiency criteria. The results suggest that the equity rule is partially followed: The richer regions are found to be assigned more loads and the poorer provinces undertake fewer burdens (ability to pay). Unfairly, the provinces with more emissions are not assigned more burdens. The current allocation scheme has not reflected any market efficiency as there is weak evidence that the burdens are higher for provinces with higher abatement costs. Finally, we identify some political factors that may affect the distribution scheme. For instance, the Chinese government considers social stability caused by enviromental conflict, among others.

The findings of this paper have important implications. First, our results indicate that the present top-down allocation scheme of the Chinese government may not be cost effective to reach its CO_2 abatement target. For instance, the current allocations that satisfy some equity rules do not consider the efficiency factors that can lower the total abatement cost. The market allows the provinces to trade emission permits to lower the abatement cost. Therefore, further economic reform to increase the role of market economy is necessary. Second, our analyses reveal enriched behind-the-scenes information and deepens the understanding of the Chinese policy-making process, which adds a new case for the Chinese political system studies.

The present paper is organized as follows. Section 2 introduces the current CO_2 allocation schemes across the provinces and the related literature. Section 3 proposes the theoretical hypotheses. Section 4 sets up the shadow price model that estimates the abatement potential and marginal cost, which are used in Section 5 for evaluating efficiency criteria. Section 5 conducts regression analysis to examine the role that equity and efficiency play in the policy-making process. The conclusion follows in Section 6.

2. Background and Literature

In order to determine the degree to which the Chinese government follows equity and efficiency rules in CO_2 allocation, we compare China's burden-sharing scheme for CO_2 intensity reduction across provinces (shown in Figure 1) with the European Union (EU) (shown in Figure

2). Figure 1 shows the final burden-sharing scheme (CO_2 intensity reduction) for 31 provinces versus GDP per capita. As we can see, it is not clear if the equity rules are adopted because it seems to be a uniform distribution among the provinces. Four less-developed regions, Tibet, Qinghai, Hainan and Xinjiang are located far from the dotted line and are allocated a significantly lower constraint (10-11%). But, below these four points, some of their poorer counterparts are observed to undertake a 16-17% burden. On the other hand, the group with high GDP per capita, like Guangdong, Zhejiang, Jiangsu, Tianjin and Shanghai, are assigned a relatively tight burden (19-19.5%). The remaining sample, excluding the four upper-left provinces, are evenly distributed around the dotted line even though all trends seem to be negative between the CO_2 reduction goals and GDP per capita.

[Figure 1 is about here]

Unlike China's intensity target distribution among regions, the EU sets an emissions cap for members (20%). The EU's burden-sharing scheme, which is established on the solid basis of several bottom-up models and the Triptych approach, has been widely evaluated and equity rules are adequately addressed (Phylipsen et al., 1998; EU, 1999; Marklund and Samakovlis, 2007; EU, 2008). Figure 2 plots CO_2 reduction distributions among EU members versus GDP per capita. There are two marked differences and features between Figure 1 and Figure 2. First, the distributed goals for Chinese provinces are all negative, indicating that all provinces must reduce their carbon intensity, while EU members are allowed to increase or decrease their emissions. The second difference, but the most important, is that EU's allocation scheme shows a strong negative relationship between the reduction target and per capita GDP. The comparison shows that the Chinese government follows certain equity rules but they are not as fair as those in the EU. Moreover, it is not evidenced from the uniform distribution that the central government has considered differential abatement costs across China's provinces, where EU's burden-sharing agreement has taken account both efficiency and equity aspects (Marklund and Samakovlis, 2007).

[Figure 2 is about here]

Many researchers discuss the rationality of the present regional allocation scheme that has been in place since 2010 and reflect that the current allocation is not cost-effective.[2] Zhang et al. (2013) evaluates various CO_2 intensity target allocation plans by developing the China Regional Energy Model (C-REM). Their simulation exhibits that more loads are allocated to those regions with relatively expensive abatement costs, while provinces with greater abatement opportunities undertake less burden. To investigate the impact of the CO2 intensity allocation scheme on regional development, Yuan et al. (2012) compares the industry-based and region-based scenarios through a multi-regional CGE model. They suggest that a two-step mixed allocation scheme should be adopted to narrow the regional development gap. Wang et al. (2013) utilizes a Data Envelopment Analysis-based optimization model and proposes a new scheme for the provincial CO_2 emissions permit allocation by 2020. They formulate disparity targets and assign them to each province to meet the CO_2 intensity, energy intensity and non-fossil fuel mix constraints, based on different scenario assumptions on economics, energy and environmental trends. These studies suggest that the current burden-sharing scheme does not appropriately assign the intensity target to each province from a cost-effective perspective.

Given China's current opaque and secretive political system (Richburg, 2012; Lawrence and Martin, 2013), there are no clear and transparent channels for the public to obtain information on how the targets are set and what principles have been taken into account during the decision-making process. The Chinese government announced that the national goal is fairly disaggregated

[2] Many previously relevant studies assess the credibility and feasibility of China's carbon intensity target from policy options and technology options (Qiu, 2009; Cohen-Tanugi, 2010; Dai et al., 2011; Jennings et al., 2011; Zhang, 2011).

after factoring in regional disparities in resources, development stage, industrial structure, and minority areas (Lan, 2012). However, a few isolated words leaked to the media disclosed that the final decisions are made by consensus after a three-stage bargaining process between provinces and the National Development and Reform Commission (NDRC).[3] One of the major concerns for central authorities is to ensure "no complaint" among provinces when they are compared to their similar counterpart (Feng and Yuan, 2011). This story is consistent with China's longstanding distinct political feature of maintaining political stability by the eventual decision-making group (Lieberthal and Oksenberg, 1988; Lieberthal, 1997; Ahrens, 2013). Therefore, there is neither an official rule nor scientific evidence on how the government designs the distribution scheme. This paper tries to determine the mechanism of this complicated economic and political decision.

3. Hypotheses

The core principle of "common but differentiated responsibilities", used widely in the international climate negotiation, is also applicable to the carbon intensity burden-sharing among regions. To reach an acceptable and feasible regime for each party, the equity and efficiency rules have to be emphasized. Based on the equity and efficiency principle, this section proposes several hypotheses in line with the Chinese government decisions.

3.1 Equity

The fundamental equity principles are defined as the normative criteria for how society should be organized and how goods or burdens should be distributed (Rose, 1990). In light of the UN

[3] First, the provincial governments are requested to submit their proposed target to the central government. Most provinces proposed to follow the national goal, however some provinces proposed higher/lower targets. The NDRC accepted those provinces that committed to a higher target and negotiated a new target with the provinces that had committed to the national level. This process was then repeated. After three rounds of bargaining, the final figure was examined and approved by the National People's Congress before being announced as part of official provincial tasks.

Framework Convention on Climate Change (UNFCCC) and modern ethical and legal codes, all people—regardless of race, age, gender or wealth—enjoy equal rights for the common atmosphere resource (Baer et al., 2000). Substantial literature has contributed to develop diverse equity principles to define "common but differentiated responsibilities".

According to China's consistent advocate on the climate issue, two major equity hypotheses are proposed below.[4]

H1: The more (historical) emissions, the more burdens should be allocated.

The egalitarian rule, or per capita entitlement criteria, argues that people have equal rights to use atmospheric resources. An equitable allocation should result in equal per capita (accumulated) emissions. Most studies claim that the adoption of this principle can ease the path for various communities to reach a common abatement agreement (Baer et al., 2000; Metz, 2000). By applying this international consensus on regional allocation cases, we anticipate that the province with higher per (accumulated) capita CO_2 emissions is more likely to have a strict target imposed on them. Similarly, the province with lower per (accumulated) capita CO_2 has a lower burden to reduce its emissions.

Due to the absence of historical emissions at the provincial level, this paper adopts the per capita CO_2 to represent the egalitarian rule following most of the previous literature (Baer et al., 2000; Chakravarty et al., 2009; Wei et al., 2012). An alternative variable, per capita accumulated surviving CO_2, will be estimated for robust check. Following the above discussion, we expect a positive coefficient with its target burden.

H2: The greater the ability to pay, the more load should be assigned.

Another widely accepted equity principle in international climate negotiation is "ability to pay",

[4] The sovereignty (grandfathering) rule, which insists that current emission permits should be proportional to history emissions, is strongly opposed by China and other developing countries. Thus, we do not apply this rule in current regional allocation plans.

which entails that the abatement load should be affordable and commensurate with economic circumstances (Rose et al., 1998; Winkler et al., 2002; Shue, 2008). Under this assumption, the richer provinces have greater monetary ability to undertake the abatement cost (Wei et al., 2012). Consequently, more loads will be assigned to the developed regions. This paper uses the per capita GDP to proxy the ability to pay principals and thus a prior expectation for the coefficient is to be positive.

3.2 Efficiency

The efficiency principle is another pillar of climate mitigation regime and has been well documented under the United Nations Framework Convention on Climate Change (UNFCCC) (Shukla, 2005). It says: “policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost”.

H3: The greater marginal abatement cost, the less target assignments will be.

Under the global constraint of being able to ensure a different concentration or temperature stabilization target, the distribution schemes with various equity principles will inevitably impose different economic impacts on countries (Mattoo and Subramanian, 2011). According to the environmental economics theory, the marginal costs of reducing CO_2 emissions should be equalized across regions to reach the desired target at the minimum overall abatement cost (Baumol and Oates, 1988). Thus, a province associated with relatively higher marginal abatement costs should take on fewer burdens (Perman, 2003).

The marginal abatement cost approach has been widely used in the international climate negotiation and for scenario analysis. It helps in quantitatively assessing the cost-effectiveness of various policy regimes (Ellerman and Decaux, 1998; Rose et al., 1998). For instance, Marklund and Samakovlis (2007) use the marginal abatement cost to represent the efficiency indicators when evaluating the EU burden-sharing agreement. They find that the countries with a higher marginal cost were assigned easier targets and they conclude that the efficiency rule is addressed. Similarly, Wei et al. (2012) uses the marginal abatement cost to construct an efficiency index to present the distribution of CO_2 intensity target among Chinese provinces.

H4: The larger the abatement potential, the tighter constraints will be.

The reduction potential of CO_2 is another useful indicator associated with the marginal abatement cost to measure the efficiency/performance level in terms of CO_2 emissions. i.e., the commonly used Global Greenhouse Gas Abatement Cost Curve consists of the abatement potential and marginal cost for various abatement options (Criqui et al., 1999). It reflects the currently available energy-conservation and carbon-free technology options, and interfuel substitution possibility (Guo et al., 2011). This information should naturally be taken into account when sharing the burden among regions. In general, keeping other conditions the same, the provinces with larger abatement potential should be given a higher burden-sharing target since it contributes more to the national goal. Therefore, we raise two hypotheses (H3 and H4) on the efficiency principal. Two proxy variables, marginal abatement cost and abatement potential are used to test H3 and H4 below.

3.3 Political factor

The carbon intensity goal is one of China's national environmental goals, which may be a lower priority than other political goals (Richerzhagen and Scholz, 2008). If some specific regions are associated with sensitive political aspects, i.e., national security or political stability, the environmental issue may be sacrificed. Under this setting, we propose the following hypotheses below.

H5: The greater the income inequality, the fewer requirements will be imposed.

The pollutant abatement activities are normally associated with economic cost. If one region's economy is highly vulnerable, the additional burden may trigger serious economic depression and social problems, which may cause the unemployment rate to increase, or widen the urban-rural income gap, especially when external financial support is inadequate. Income inequality then exacerbates political instability by aggravating social discontent (Alesina and Perotti, 1996). In this case, the central government is cautious in setting up a larger CO_2 goal for the region. Since China's official reported unemployment rate only accounts for the registered urban unemployed, this paper adopts the ratio of disposable income of urban residents over the net income of rural residents. [5] This urban-rural income gap indicator is used to proxy the income inequality, and a negative relationship is expected.

H6: The greater the fragile/alienation of society is, the lower the target will be.

Increasing terrorism activities in border regions have become a threat to the stability of authorities. As Ades and Chua (1997) revealed, the political instability in neighboring countries will result in a negative spillover effect. In this context, the central and local governments will put their major focus on the national security issue, i.e., expand local military defense and anti-terror activities, thus the carbon intensity goal is relatively less important. This paper adopts the numbers of neighboring foreign countries to proxy the society's instability circumstance outside. The countries with more borders are assumed to have the higher external threat.

Another internal instability force is the ethnic conflicts in some minority areas. As Hero and Tolbert (1996) argued, the political processes and outcomes are significantly influenced by the ethnic diversity in the U.S. To investigate the role minority diversity played in China's policy-

[5] The national unemployment rate, as reported by the official statistical bureau, maintains a narrow fluctuation in the past decade (2003-2013) and ranges from 4.0-4.3%.

making process, we use a commonly used index, the ratio of the minority population size in minority nationality autonomous areas to the dominant Han population (Sullivan, 1973), to measure the diversity for each provincial racial population. It's expected that greater minority diversity is associated with less burden from the environmental aspect.

H7: The more intensive the environmental conflict, the more burden there will be.

Besides the economic and social aspect, the increasing environmental degradation and overuse of environmental capacity also become crucial sources of political instability. One would expect that, in a highly polluted area, the citizens are eager to vent their discontent and express their demands through multi-channels, either in public or in private. Consequently, the deteriorating environmental situation may lead to widespread mass incidents and violent protests, especially when the dialogue channel is seriously absent. It has been viewed as a new security threat by central government (Ma, 2008). To soothe sentiment fluctuations, the central authorities expect to show their determination on environmental protection by setting up a tighter constraint for the polluter (Yang, 1995). Here we use the case number of environmental administrative penalties per 100 people to picture the environmental conflict. The data are collected from the China Environment Yearbook. Positive coefficients are anticipated.

H8: The greater the bargaining power/possibility is, the larger the requested goal.

The final burden-sharing allocation may be linked to the network and negotiation power between the central government and the local governments. Central government has the power in promoting or demoting the local government leaders based on some economic indicators. During the provincial leaders' five-year terms of office, the local governments try to request a relatively lower goal so that it is easier to have a better economic indicator measured by GDP. Especially if the local government official has a strong connection with the central government, then he may be able to negotiate a relatively lower goal. However, if the local government's leader is expected to be promoted soon and leave the position, he may request a relatively higher target to please the central government and leave the responsibility to the future local government leader.

We thus collect two personal characteristic variables for the most powerful local leader—secretary of the provincial party committee. To test how the bargaining power affects the final allocation, we define a dummy variable ***Politburo***, which is 1 if they are the members of the political bureau of the CPC central committee (the top leadership bodies), 0 otherwise. We assume that a politburo member has greater power to negotiate with the central government and request a lower target. Another variable is the leader's ***Age***, which is used to proxy the promotion possibilities. A negative sign is expected since a younger leader may tend to be more ambitious and an older leader may be more conservative. These data are collected from the official profiles for political heads from the People's Website.[6]

4. Model Specification

Most of the proxy variables mentioned in section 3 can be collected from statistical yearbooks; however, the efficiency components have to be estimated. In this section, we will first derive the shadow price and inefficiency level on the basis of directional distance function.[7] It is used to construct the marginal abatement cost and abatement potential. Finally, an econometric model is specified to identify and examine the determinants of the policy-making process.

[6] Detailed personal statements for political heads can be accessed via: http://politics.people.com.cn/GB/8198/351134/index.html

[7] There are three approaches to derive the marginal abatement cost: the engineering bottom-up approach, the model-derived approach and the production-based approach. The present paper uses the production-based approach since it is solidly based in production theory, compact specification and its interpretation is straightforward. For more details on the comparison refer to Du et al. (2015).

4.1 The directional output distance function

The production technology is given by an output set $P(x)=\left\{(y,b): x \in \Re_{+}^{N}\ can\ produce\,(y,b) \in \Re_{+}^{M} \times \Re_{+}^{J}\right\}$, where $x \in \Re_{+}^{N}$ is a vector of input, $y \in \Re_{+}^{M}$ is a vector of good output and $b \in \Re_{+}^{J}$ is a vector of bad output. This technology is assumed to be convex and compact. Furthermore, the inputs and good outputs are freely disposable. This assumption infers that it is possible to increase the inputs or reduce the good outputs with other conditions remaining unchanged.

Two environmental axioms are imposed on the *P(x)* to accommondate the production of bad outputs (i.e. pollutant). The first axiom is the good and bad outputs satisfy joint weak disposability, i.e., $if\ (y,b) \in P(x)\ and\ \theta \in [0,1],\ then\,(\theta y, \theta b) \in P(x)$. Weak disposability means that any proportional reduction of good and bad outputs together is feasible. Another axiom is that bad outputs are jointly produced with good outputs, that is: $if\ (y,b) \in P(x)\ and\ b=0,\ then\ y=0$. It implies that no good output can be produced without simultaneously creating bad output. The directional output distance function is defined by Chung et al. (1997):

$$D_o(x,y,b;g_y,-g_b)=max\left\{\beta:(y+\beta g_y, b-\beta g_b) \in P(x)\right\} \tag{1}$$

Given the environmental production technology *P*(*x*), the directional output distance function aims to reach the boundary of *P*(*x*) along with the directional vector $g=(g_y,-g_b)$. The value of β^* measures the maximum distance from any observation within the boundary to its refereed point on the frontier. Thus it serves as a measure of inefficiency. A positive D_o indicates that the sample can simultaneously expand good output *y* and cut bad output *b* by β^* so as to hit the frontier along the g direction.[8] The higher the value is, the less efficient the output vector is. It takes the value of zero when it performs the best and lies on the boundary.

The directional output distance function inherits its properties from $P(x)$ (Färe et al., 2005). That is, $D_o(x, y, b; g)$ is concave and non-negative. It is monotonically corresponding to the free disposability of inputs and good outputs and the weak disposability of bad outputs, respectively. Finally, it satisfies the translation property:

$$D_o(x, y+\alpha \cdot g_y, b-\alpha \cdot g_b; g) = D(x, y, b; g) - \alpha \qquad (2)$$

where α is a positive scalar. This property shows that if good output is expanded by αg_y and bad output is contracted by αg_b, then the value of D_o will be more efficient in the amount α. It is the additive analogue of the multiplicative homogeneity property of the Shephard output distance function (Färe et al., 2005).

4.2 The shadow price model and abatement potential

Let vectors $p \in \Re_+^M$ and $q \in \Re_+^J$ denote the price of good and bad outputs, respectively. The revenue function can be specified as $R(x, p, q) = \max_{y,b}\{py - qb : \vec{D}_o(x, y, b; g) \geq 0\}$. Because many observations have a non-negative inefficiency, the efficiency improvement along the direction g is feasible; i.e. if $(y, b) \in P(x)$, then $(y + \beta g_y, b - \beta g_b) \in P(x)$. The revenue function can be rewritten as $R(x, p, q) \geq (py - qb) + p \cdot \vec{D}_o\left(x, y, b; g\right) \cdot g_y + q \cdot \vec{D}_o\left(x, y, b; g\right) \cdot g_b$. It shows that the maximum feasible revenue (the left side) is no less than the observed revenue plus efficiency gains from an increase in good output along g_y and a decrease in bad output along g_b.

[8] This is the major feature and advantage of the directional output distance function. Compared with the Shephard output distance function which seeks to expand both good outputs and bad outputs simultaneously, the directional output distance function credits firms to increase the good outputs along vector g_y while simultaneously reducing the bad outputs along vector g_b. Thus, it provides a more reliable measure of true productivity (Chung et al., 1997).

By rearranging the revenue function, the directional distance function can be derived from the revenue function: $\vec{D}_o\left(x,y,b;g\right) \le \frac{R(x,p,q)-(py-qb)}{p\cdot g_y + q\cdot g_b} = \min_{p,q}\left\{\frac{R(x,p,q)-(py-qb)}{p\cdot g_y + q\cdot g_b}\right\}$. We can then get two first-order conditions by applying the envelope theorem twice for good and bad outputs, respectively, that is: $\nabla_y \vec{D}_o\left(x,y,b;g\right) = \frac{-p}{p\cdot g_y + q\cdot g_b}$ and $\nabla_b \vec{D}_o\left(x,y,b;g\right) = \frac{q}{p\cdot g_y + q\cdot g_b}$. The shadow price of the *j*-th bad output can be specified as (Färe et al., 1993)[9]:

$$q_j = -p_m \cdot \left(\frac{\partial D_o\left(x,y,b;g\right)/\partial b_j}{\partial D_o\left(x,y,b;g\right)/\partial y_m} \right) \tag{3}$$

In a perfect competitive market, the observed market price of the *m*-th good output equals its absolute shadow price p_m. Consequently, we can represent the shadow price for the *j*-th bad output by the product of our normalizing price of *m*-th good output and the marginal transformation rate between *j*-th bad output and *m*-th good output.[10] The shadow price specification in equation (3) captures the loss value in terms of y_m when cutting b_j marginally on the boundary of $P(x)$. It reflects the trade-off relationship between bad output *j* and tradable good output *m* and thus can be treated as the marginal abatement cost (Marklund and Samakovlis, 2007).

Since the value of β^* measures the maximum feasible reduction of bad output, one may construct the partial technical efficiency for the *j*-th bad output and its supplemental counterpart—the abatement potential (Wei et al., 2012). That is,

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[9] Alternatively, we can re-rewrite model (3) as: $-q/p = \partial D_o\left(x,y,b;g\right)/\partial b \big/ \partial D_o\left(x,y,b;g\right)/\partial y$. The ratio of the shadow price (*-q/p*) for any observation describes the slope of the tangent line at the boundary of *P(x)*. It reflects the trade-off between the bad output and good output, respectively, on the frontier of *P(x)* where the production is technically efficient.
[10] In our case, we have one good output (GDP) and one bad output (CO_2). We assume the shadow price of GDP equals its market price and equals 1. Thus, the shadow price of bad output (CO_2) can be expressed in Yuan.

$$PTE_j^{k,t} = \frac{projected\ bad\ output}{actual\ bad\ output} = \frac{b_j^{k,t} - \beta_j^{*k,t}}{b_j^{k,t}} \quad (4)$$

$$AP_j^{k,t} = \frac{feasible\ reduction\ of\ bad\ output}{actual\ bad\ output} = \frac{\beta_j^{*k,t}}{b_j^{k,t}} = 1 - PTE_j^{k,t} \quad (5)$$

where ***PTE*** represents the relatively efficient level in terms of *j*-th bad output production, and ***AP*** measures the maximum feasible abatement potential using current available technologies compared with the best-performing samples. Since the ***AP*** is expressed as the maximum percentage that can be reduced of the real bad output, its values are between 0 and 1. A higher score of ***AP*** means the sample has more removable bad output through efficiency improvement (thus a higher ***AP*** indicates larger inefficiency). It should be noted that a zero value of ***AP*** does not mean that the sample cannot further reduce its bad output. Rather, it indicates that the sample is Pareto-Koopmans efficient among all of the comparison samples (Charnes et al., 1985).

To estimate the shadow price in equation (3), a differentiable function of $D_o(x, y, b; g)$ is needed. The present paper adopts the quadratic function to parameterize the directional output distance function.[11] As in Färe et al. (2005), we set the directional vector (g_y,-g_b)=(1,-1) to seek a simultaneous expansion in good output and abatement of the pollutant.[12] In our case, we have *k*=1,…,30 provinces produce one good output (*y*) and one bad output (*b*) with three inputs (*x*), then the quadratic directional distance function is specified as:

[11] One can choose either the parametric or the non-parametric approach to represent the directional output distance function. The non-parametric method, such as Data Envelopment Analysis (DEA), is driven by the data itself and does not require any prior function form. However, the parametric method is more common when deriving the shadow price since its parametric specification is easy for derivation. On the choice of function form, the translog and quadratic functions are two widely used models that represent the output distance function. However, the translog function violates the translation property and the quadratic model outperforms translog parameterizations when modeling the production technology (Färe et al., 2010).

[12] The setting of the directional vectors may vary and it depends on the purpose. We choose the directional vectors to be uniform, i.e., $g_y=1_M$, $g_b=1_J$. This choice is in line with environmental regulations that require pollutant reduction. In addition, it is easy to aggregate the individual unit's efficiencies (Färe et al., 2005).

$$
\begin{aligned}
D_o(x^{k,t}, y^{k,t}, b^{k,t}; 1, -1) = \alpha_0 + \sum_{n=1}^{3} \alpha_n x_n^{k,t} + \beta_1 y_1^{k,t} + \gamma_1 b_1^{k,t} \\
+ \frac{1}{2} \sum_{n=1}^{3} \sum_{n'=1}^{3} \alpha_{nn'} x_n^{k,t} x_{n'}^{k,t} + \frac{1}{2} \beta_2 (y_1^{k,t})^2 + \frac{1}{2} \gamma_2 (b_1^{k,t})^2 \\
+ \sum_{n=1}^{3} \delta_n x_n^{k,t} y_1^{k,t} + \sum_{n=1}^{3} \eta_n x_n^{k,t} b_1^{k,t} + \mu y_1^{k,t} b_1^{k,t} + \kappa_k + \tau_t
\end{aligned}
\tag{6}
$$

where parameters κ_k and τ_t are used to capture the individual and time effects, respectively. Following Aigner and Chu (1968), the unknown parameters in equation (6) are estimated with a deterministic linear programming (LP) approach by minimizing the sum of the deviation of the individual observations from the frontier.

$$
\begin{aligned}
&\min \sum_{k=1}^{K} \sum_{t=1}^{T} \left[D_o(x^{k,t}, y^{k,t}, b^{k,t}; 1, -1) - 0 \right] \\
&s.t.\ (i) \quad D_o(x^{k,t}, y^{k,t}, b^{k,t}; g) \geq 0,\ k = 1, \ldots, K; t = 1, \ldots, T \\
&\quad (ii) \quad \partial D_o(x^{k,t}, y^{k,t}, b^{k,t}; g) / \partial b \geq 0,\ k = 1, \ldots, K; t = 1, \ldots, T \\
&\quad (iii) \quad \partial D_o(x^{k,t}, y^{k,t}, b^{k,t}; g) / \partial y \leq 0,\ k = 1, \ldots, K; t = 1, \ldots, T \\
&\quad (iv) \quad \partial D_o(\overline{x}^{k,t}, y^{k,t}, b^{k,t}; g) / \partial x_n \geq 0,\ n = 1, \ldots, N; k = 1, \ldots, K; t = 1, \ldots, T \\
&\quad (v) \quad \beta_1 - \gamma_1 = -1,\ \beta_2 = \mu = \gamma_2,\ \delta_n = \eta_n,\ n = 1, 2, 3 \\
&\quad (vi) \quad \alpha_{nn'} = \alpha_{n'n},\ n, n' = 1, 2, 3
\end{aligned}
\tag{7}
$$

The first constraint ensures that all observations are feasible. The monotonicity assumption in bad outputs, good outputs and inputs are imposed by the inequality (ii) - (iv), respectively. The restrictions given by (v) and (vi) impose translation property and symmetry conditions, respectively.

4.3 The preference identification model

To investigate the role of equity and efficiency principles played in shaping the regional burden-sharing scheme, an econometric model is specified as follows:

$$
tar_k = \phi + \lambda \cdot Equity_{k,t} + \omega \cdot Efficiency_{k,t} + \rho \cdot Politic_{k,t} + \psi \cdot X_{k,t} + \varepsilon_{k,t}
\tag{8}
$$

where *tar* denotes the assigned 12th FYP CO_2 intensity target for *k*-th province. The vectors *Equity*, *Efficiency* and *Politic* correspond to the equity, efficiency and politic hypothesis in section 3, respectively. The vector *X* includes control variables that the policymakers may consider. For instance, we control for structural characteristics measured by the share of industrial value-added in GDP. Considering China as a coal-dominated country, we control the fuel mix by adopting the coal share in total end-user energy consumption. The error term ε is assumed to be uncorrelated with all independent variables and uncorrelated in time and across regions (Marklund and Samakovlis, 2007).

The prior expectations for the regression are following the discussion in Section 3. The coefficients of equity index are expected to be significantly positive in the case that equity rule is well addressed. That is, the provinces with lower per capita CO_2 levels should be allocated less burdens, and the historical per capita emissions should be positively associated with the allocation target. The coefficients for the efficiency variable are expected to be significantly negative for the marginal abatement cost and significantly positive for the abatement potential. If the government considers the efficiency criteria, the provinces with higher marginal abatement costs should take on less burdens. Similarly, the provinces with higher abatement potential should be allocated more burdens. We adopt several measurements in considering political effect on our regression and expect to see significant negative coefficients of the index measuring income inequality and social instability. For instance, the higher the number of environmental administrative penalties should expect to induce a tighter target.

5. Results and Discussion

5.1 First stage: estimate the marginal abatement cost and abatement potential

The data covering 30 provinces for the period 1997 to 2010 are used in estimating model (7) in the first stage. [13] The three inputs are labor, capital stock and energy consumption, and the two output variables are economic output (GDP) and CO_2 emissions. The labor input is measured by the number of employed. The GDP is deflated to the constant 2005 price. Both variables are obtained from China Statistical Yearbooks (NBS, 2012b). The energy consumption information is collected from China Energy Statistical Yearbooks (NBS, 2012a). Since the capital stock is unavailable from statistical books, the widely accepted Perpetual Inventory Method (PIM) is used to estimate the stock of fixed assets at the 2005 price.[14]

The data on CO_2 emissions at the provincial level are unavailable. To tackle this, the CO_2 emissions from major fossil-fuel, combined with the cement production, are estimated according to International Panel on Climate Change (IPCC) guidelines. Specifically, the CO_2 emissions from fossil fuel can be estimated from the formula: $CO_2 = \sum E_i \times CF_i \times CC_i \times COF_i \times \left(44/12\right)$, where subscript i indexes six types of fossil fuel including coal, gasoline, kerosene, diesel, fuel oil and natural gas. *E*, *CF*, *CC* and *COF* represent fuel consumption in physical units, transformation factor, carbon content and carbon oxidation factor, respectively. The term 44/12 is the ratio of the mass of one carbon atom combined with two oxygen atoms to the mass of an oxygen atom. We also consider the inter-provincial electricity trade. For the net electricity exporter in a given year,

[13] There are 31 provinces, autonomous regions, and municipalities on the Chinese mainland. This study does not include Hong Kong SAR, Macao SAR or Taiwan Province. Tibet is excluded because of the absence of energy data. The starting year is set as 1997 for two reasons. One is that the Chongqing was settled as a municipality in 1997. The other reason is that most detailed end-user energy consumptions are unavailable before mid-1990s.

[14] The estimation of capital stock is given as: $K_{i,t} = K_{i,t-1}(1-\rho_i) + I_{i,t}$, where *I*, *K* and ρ are investment, capital stock and depreciation rate for province *i* in year *t*. The data of initial capital stock and depreciation rate come from Zhang et al. (2004). The annual investment is collected from the China Statistical Yearbook. All serial data are converted to 2005 prices.

the embedded emissions associated with the exported electricity quantity are deducted from that province's total emissions (Du et al., 2012). All of the energy consumption data are taken from the energy balance tables by regions in the China Energy Statistical Yearbooks. The cement production data are collected from various Statistical Yearbooks from each province over various years.

Table 1 summarizes the statistics for all three inputs and two outputs. A quick expression is, the labor declined slowly in the first several years and then continuously increased. Driven by a 13.5% annual growth rate of capital stock, the GDP increased 10.8% per year. During this period, the energy consumption grew at an annual rate of 7.7%, associated with an annual rate of 7.2% for CO_2 emission. Accordingly, the mean provincial CO_2 intensity declined before 2002 after experiencing a deep climbing during 2003-2005, it shows a downward trend.

[Table 1 is about here]

The GAMS/MINOS-solver is adopted to solve the linear problem at system equation (7). All input/output variables are normalized by their mean value to overcome the convergence problem. This normalization implies that $(x, y, b) = (1, 1, 1)$ for a hypothetical province that uses mean inputs and produces mean outputs. The results of parameter estimates are provided in Table 2. Note that the parameters in the table are computed from the linear programming. It differs from econometrics estimation coefficients in that a positive/negative parameter for one province (year) does not represent that it is less/more efficient than the benchmark. The value of inefficiency (directional distance function) for various provinces and years can be calculated using these parameters.

[Table 2 is about here]

Table 3 summarizes the estimation of directional distance function, marginal abatement costs and abatement potential by region and period.[15] First, the estimated value of the directional distance function (0.0618) is close to other similar studies. For example, Murty et al. (2007) reports an inefficient estimate of 0.06 for a representative India power generation firm. Marklund and Samakovlis (2007) report an inefficient value range of 0.02-0.06 for EU members. Our results indicate that, for a hypothetical province who used the mean inputs to produce mean outputs during 1997-2010, it could, on average, expand its GDP by 39.14 (633.33*0.0618) billion Yuan and cut its CO_2 by 9.08 (146.904*0.0618) million tons. Second, the average marginal abatement cost indicates that the hypothetical province can cut an additional one ton of CO_2 emissions with the cost of 1359.7 Yuan.[16] Among three regions, the east area (2376.4 Yuan/ton) registers a higher cost for cutting an additional one unit of CO_2, followed by the middle (1032.5 Yuan/ton) and west (597.4 Yuan/ton). From the timeline view, the cost to reduce the carbon is becoming more expensive. Third, the average abatement potential during the whole period is 7.39, which suggests that the hypothetical province can relatively reduce its CO_2 by 7.39% when compared with the best-performance provinces. There exists remarkable regional disparity. During 1997-2010, the east region holds the larger potential for further emissions control than the middle and west area on average. However, we have to point out that the east region has lower abatment potential than the middle and west area after 2006. This may result from the regional development gap, industry

[15] The east region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The middle region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan. The west region includes Inner Mongolia, Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

[16] As equation (3) shows, the shadow price is expressed as a ratio. In the case of the denominator $\partial D_o\left(x, y, b; g\right)/\partial y_m$ equals zero, the shadow price is not available. We use the estimated coefficient in Table 2 to compute equation (3) and find that six observations miss the shadow price value. They are: Liaoning (2000), Jiangsu (2010), Guangdong (2009, 2010), and Sichuan (2005, 2006).

transfer and absence of available technical options.[17] However, along with more measures and efforts been implemented, it leaves less space and more difficulties for further abatement activities.

[Table 3 is about here]

5.2 Second stage: identifying the preference

We conduct the regression analysis on model (8) based on the marginal abatement cost and abatement potential estimated in Section 5.1. Table 4 summarizes the independent variables. The variables are selected from the theory postulation in Section 2.

[Table 4 is about here]

Since the target for period 2010-2015 was set in 2010, model (8) assumes that each province's target in the future is a linear function of its historical behaviors and performance. However, it is uncertain how much historical information was obtained and to what extent the decision-makers adopted the historical information. We set up three scenarios for our analysis. First, we assume that the latest information may exert the greatest influence. In this case, the one-year lag item (2009 data) is used to explain the decision made in 2010. In the second case, the variables are measured by the average level of the past five years (2005-2009). The third scenario picks up all available 13-year average data (1997-2009). In each case, we have a cross-section dataset covering 30 provinces. Given our small sample size, the regional effect (east, middle and west) instead of the individual provincial effect is controlled.

[Table 5 is about here]

[17] Note that the abatement potential is declining for the east region and is increasing for the middle and west regions from 1997 through 2010. The east region has a higher abatement potential before 2006 since it was associated with higher industrial composition, compared with the agriculture-based middle and west regions. However, along with the industrial upgrading and transfer, increasing inefficient sectors in the east region were moved to the middle and west regions, abatement potential for the east region has declined over the years and now has a lower abatement potential than the middle and west regions since 2000.

Table 5 displays the initial regression result. Columns (1), (3) and (5) show estimations for all variables by using one-year lag, the past five-year average and the past 13-year average as independent variables, respectively. Columns (2), (4) and (6) list each type's compact specification with selected variables by using a stepwise regression procedure. Looking at the statistical information for each regression, we find that column (2) has the greatest explanation power as it has the largest adjusted-R^2 and the smallest AIC and BIC criterion. It suggests that the one-year lag data fit the model better than the five-year average and historical average. Thus, we will adopt the one-year lagged data.

Column (2) in Table 5 reveals the potential driving force for the CO_2 intensity distribution. It includes the per capita CO_2 and income, minority percentage, environmental penalty number, coal share in fuel and industrial composition. It should be noted that this OLS regression result is sensitive to outliers as the sample size is small. To eliminate the impact of outliers and gain robust estimators for a small sample, the least absolute deviations (LAD) estimator is preferable as an alternative approach (Greene, 2011, p 203). We resample the data with 500 bootstrap replications and report both OLS and LAD in columns (1) and (2) in Table 6, respectively.

Besides the bootstrap LAD, another approach is used to enrich the sample size for a robust check. The energy-intensity target data for the 11^{th} FYP (2005-2010), which was distributed among provinces in 2005, are used to proxy the CO_2 intensity. The reason to do so is that the energy intensity trend is parallel with (or consistent with) CO_2 intensity when energy mix does not change.[18] We pool the 2005 and 2010 targets for 30 provinces as dependant variables. The one year lag of independent variables is used for selected variables as shown in Table 5.

[18] The CO_2 intensity can be represented as the energy intensity multiplied by the CO_2 emission per energy in line with KAYA identity. That is: $(CO_2/Y)=(CO_2/E)*(E/Y)$. In case of stable fuel emission factors and fuel mix, the trend of CO_2 intensity is consistent with the energy efficiency.

Moreover, we add a dummy variable *d2005* to distinguish two allocation themes. It equals 1 for 2005 energy intensity allocation and 0 for 2010 CO_2 intensity distribution. The OLS and bootstrap LAD are listed in columns (3) and (4), respectively.

The historical emissions are as important as or even more important as current emissions since historical emissions can stay in the atmosphere for centuries and further aggravate the greenhouse effect (Chinadaily, 2013). However, this historical emissions stock indicator is less popular than emissions flow because it is difficult to define and measure accurately. Here we construct an alternative variable, the per capita historical CO_2 emissions ($H1b\_rhCO_2$) to replace the per capita CO_2 ($H1a\_rCO_2$) for robust check.[19] Columns (5) and (6) in Table 6 apply the OLS and LAD for 2010 data, respectively. Similarly, columns (7) and (8) in Table 6 report the OLS and LAD for pooled data, respectively.

[Table 6 is about here]

If we treat the OLS estimation for 2010 data in column (1) as a benchmark and compare other columns against it, the bootstrap approach is found to generate a similar estimation with less significant levels. Similarly, the pooled regression yields a consistent estimation with low explanation power. The use of alternative variables gives a very close result. Column (1) seems to perform the best among all specifications in terms of its statistical information.

[19] The attenuation of CO_2 in the atmosphere is taken into account because the ocean and forest possess carbon sink functions. Following Siegenthaler (1983), the surviving emission for base year's emission $b(0)$ in year t can be estimated via $b(t) = b(0) \times (0.3e^{-t/7} + 0.34e^{-t/71} + 0.36e^{-t/815})$ with a non-linear diminishing rate. The per capita accumulated surviving CO_2 emission in year t is defined as $\sum_{t=0}^{T} b(t) / pop_t$, where numerate is aggregated historical surviving emissions until t-th year and pop_t is population size in year t. Based on the data's availability, the annual national emissions during 1971 to 1996 are taken from IEA's dataset (IEA, 2012), while the emissions for each province afterward is our calculation. We first estimate the surviving CO_2 stock through 1996 and then split it into each province based on their emission proportion in 1997. Then we set 1996 as the base year and re-estimate the surviving emissions for the period 1997-2010 at province level. This serial is divided by the population yield of the variable of per capita accumulated surviving emission.

As we can see by comparing Tables 5 and 6, equity hypotheses H1 is not supported while H2 is strongly supported. As we discussed in Section 2, both coefficients of equity index are expected to be positive in case that equity rule is well addressed. However, the insignificant negative coefficients for *H1a_rCO*$_2$ in Table 6 reveal that the egalitarian rule is not being taken into account by the current burden-sharing scheme. The significant negative results of per capita CO_2 in column (1) in Table 6 is caused by the multicollinearity between the per capita GDP and the per capita CO_2. If we drop per capita GDP, the coefficient of per capita CO_2 becomes insignificant (the results are available upon request). Since both variables are our concern and the correlation does not change our conclusion, we thus include both of them in the same model. Similarly, the historical per capita emissions (*H1b_rhCO*$_2$) are insignificant and negatively associated with the target in Table 6. Differently, the significant positive sign for *H2_rgdp* is consistent with our expectation. Note the conclusion remains the same if we drop the per capita CO_2, which correlates with per capita GDP. That is, the per capita GDP is still significant. It shows that the "ability to pay" rule is fully considered by the policy-makers: the richer regions are assigned more loads while the poorer provinces undertake fewer burdens.

The next two coefficients in Table 5 show that the criterion of efficiency is not followed in China. It is expected that the marginal abatement cost (H3) will be negative and the abatement potential (H4) will be positive if the criterion of efficiency is fully considered during the decision-making process. However, the coefficient of marginal abatement cost (*H3_cmac)* in Table 5 shows that the marginal abatement cost is either insignificant or positively correlated with the dependent variable. The coefficients for the abatement potential (*H4_cpot)* are not significant across all estimations. These results are consistent with the literature (Yuan et al., 2012; Wang et al., 2013;

Zhang et al., 2013) and suggest that the current burden-sharing scheme does not appropriately assign the intensity target to each province from a cost-effective perspective.

We adopt several measurements in considering political effect on our regression at Table 5. As we can see, the coefficient of income inequality measurement (*H5_incomegap*) is not significant and thus it indicates that the urban-rural income gap variable was not so great as to be seriously taken into account by the central authorities. Similarly, the coefficient of *H6a_foreign* is insignificant and near zero, indicating that the social instability dimension (H6) is not supported. On the other hand, the internal society alienation, indicated by the minority area, raises the policy-makers attention when setting up the burden-sharing scheme. The variable *H6b_minority* gains a significantly negative coefficient in all columns in Table 6, as predicted by H6. Furthermore, the magnitude among all coefficients reveals that it plays a crucial role. This is consistent with previous empirical evidence in the U.S., which suggests that the heterogeneous environments may be associated with positive policy outcomes for minorities (Hero and Tolbert, 1996). Beyond the economic and social dimensions, the environment induced political instability factor (H7) is also tested. The positive coefficients for *H7b_penalty* across most columns suggest that the higher the number of environmental administrative penalties a province has, the more likely a tighter target will be allocated.

Finally, the estimation results provide weak evidence that the local leader matters in the central-local bargaining process. Column (1) in Table 5 reports a negative sign for leaders' age and politburo position variables. It indicates that the provincial leader may not exert influence when determining the CO_2 intensity target. Alternatively, we do not observe direct and confidential impact of local leaders on this provincial burden-sharing theme. Moreover, the positive sign for fuel mix (*share_coal*) suggests that the coal-dominated provinces will be punished with heavier burdens, which is consistent with Marklund and Samakovlis (2007). However, the industrial composition is not significant in most columns.

6. Conclusion

This paper investigates political decisions that the Chinese government made based on equity and efficiency in the provincial burden-sharing scheme. We proposed eight hypotheses based on the theory and literature. Using the data from Statistical Yearbooks and estimated efficiency components in the paper, 30 provinces for the period 1997 to 2010 are used in estimating the econometric model. In general, our findings suggest that the CO_2 allocation scheme considers more political factors, less equity and shows the least efficiency in their decision.

The paper consistently finds that the egalitarian rule is not taken into account for the current burden-sharing scheme. However, the “ability to pay” rule is well addressed by the policy-makers as we do find that the richer regions are assigned more loads while the poorer provinces undertake fewer burdens.

The paper finds that the policy-makers do not take the efficiency principle into consideration. We do not find significant results that either the provinces with higher costs to reduce one additional unit of CO_2 are assigned fewer goals, or provinces with relatively small abatement costs were assigned easier emissions constraints. These findings are consistent with previous similar studies, i.e., Zhang et al. (2013), which suggest that the present burden-sharing scheme may miss cost-effective opportunities since it assigned a larger load to the highly constrained and costly provinces.

The policy-makers do consider some political factors. The paper finds that the internal society alienation raised the policy-makers’ attention when setting up the burden-sharing scheme. The provinces with more minority groups are allocated less burden. The higher number of environmental administrative penalties a province has, the more likely it is to be allocated a tighter target. We do not find that social instability from the urban-rural income gap or a political leader's characteristics are associated with the CO_2 allocation. These findings also coincide with the theoretical literature on China's political system, which claims that political context should be fully accounted for in order to understand China's environmental issue (Lieberthal, 1997). It is also consistent with empirical studies, i.e., Jia (2014) empirically examined and presented evidence on the impact of China's political incentives on the environment.

The findings of the paper have important policy implications. First, for China's decision-makers, we identify the shortcomings of the current burden-sharing schemes. We should be aware of the huge difference between our allocations from the EU's. As we stated above, the equity rule is partially followed. We should pay more attention to historical emissions and require the province to take a larger burden of responsibility. We shall improve the allocation efficiency, which may rely on further reform to increase the role of market economy and allow emission trade across the provinces. Second, our paper not only presents the case of China, but also provides a good example of the climate problem and solution as documented as "global problem, local solution".[20]

Nevertheless, our study leaves several points for future exploration. For instance, instead of revealing the current preferences of decision makers, future research shall provide a scientific "optimal distribution scheme" by following the least-cost rule. One specific direction may be to

[20] Unlike the long-running international climate negotiations, China's self-commitment on energy intensity since 2005 and on carbon intensity since 2010 illustrates that China is keen on the "common but differentiated responsibilities", an initiative that has gained international respect. It reflects the China-US joint climate change agreement that both countries announced in their unilateral measures and domestic goals by 2030. Following this tune, the Lima Climate Change Conference in December 2014, saw for the first time all parties agreeing to cut the CO_2 emissions even though it was weak and many difficult decisions need to be tackled later. Thus, when it's hard to reach an agreement on a global challenge, the local solution and action that China has utilized may become a second-best strategy.

derive the provincial optimal reduction based on the marginal abatement cost curve. This may provide more clear efficiency measurement. In addition, the political factors play a more comprehensive role in the decision-making process. Its measurement and influence mechanism needs to be more carefully explored and examined in the future.

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