The effects of energy-related policies on energy consumption in China[1]

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Abstract

This paper examines the effects of different types of energy-related policies on different types of energy consumption in China. We collect and construct a novel and comprehensive data set on detailed province-level policies for specific types of energy-related command and control policies; financial incentives; awards; intellectual property rights; and education and information policies. Our econometric method employs instruments to address the potential endogeneity of the policies. According to our results, some types of energy-related policies have been effective in reducing energy consumption. However, many other policies have the possibly unintended or even perverse consequence of increasing rather than decreasing energy consumption. For example, providing education and information for increasing energy efficiency has the perverse effect of leading to a significant increase in electricity consumption per capita and in stalks consumption per capita, possibly due to a rebound effect. Our results on the mixed effectiveness of energy-related policies in China in reducing energy consumption have important implications for the design of energy-related policies in China and elsewhere.

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1. Introduction

Energy-related issues are pervasive throughout the world. In many developing countries such as China, energy consumption has been increasing rapidly, resulting in energy-related problems such as power shortages and environmental pollution. These problems have severely threatened the sustainable development of these countries and have caused great concern at all levels of society, from the general public to national governments to international agencies.

Due to the severity of energy-related problems, the governments of many developing countries have begun to introduce energy policies and regulations to combat these problems. The intention with most energy-related policies is to influence processes in such a way that leads to more efficient or more careful use of resources and to more environmentally sustainable behavior. In this paper, we examine the effects of different types of energy-related policies on different types of energy consumption in China.

There is a large previous literature on the effects of different types of energy policies, particularly in the context of the United States (see e.g., Auffhammer et al., 2016; Barker et al., 2007; Lade, Lin Lawell and Smith, 2017; Popp, 2002; Scott et al., 2008; Weyant and Olavson, 1999). There is also a growing strand of literature on the rebound effect, which may cause energy policies to be ineffective in reducing energy consumption. A "rebound" effect arises when some of the gains from improving the efficiency of energy use is lost because of behavioral responses. For example, a decrease in energy consumption due to efficiency improvement also leads to a reduction in the real cost of energy services per unit, and thus brings about an increase in the demand for energy services. Therefore, the potential energy savings and emissions reduction from efficiency improvement might be offset by responses to the cost reduction (Zhang and Lin Lawell, 2017; Gillingham et al., 2013; Lin, Yang and Liu, 2013). Similarly, an increase in energy efficiency can spur economic growth, either through a reallocation of growth through sectoral reallocation or overall growth through an increase in total factor productivity, and the economic growth requires additional energy consumption (Gillingham, Rapson and Wagner, 2016; Zhang and Lin Lawell, 2017).

While there are many studies on different types of energy policies, there are fewer empirical papers on the relationship between China's energy policies and their consequences. In its study of China's energy subsidies, the IEA (1999, chapter 5) quantifies the size of China's fossil fuel and electricity subsidies, and assesses the potential impact that a removal of the subsidy would have on energy consumption. Lin et al. (2009) argue that China's subsidy mechanism was both inefficient and unfair, and suggest that it would have been essential to adopt a more targeted subsidy policy. Lin and Jiang (2011) analyze China's energy subsidies and use a computable general equilibrium (CGE) model to simulate the overall impacts of energy subsidy reforms. Liu and Li (2011) analyze the fossil energy subsidies of China and use a CGE model to simulate the effects of fossil energy subsidy reform under different scenarios. Lin and Zeng (2014) study gasoline taxes in China. Si et al. (2017) analyze the effects of China's biofuel policies on agricultural and ethanol markets.

There is also a literature on energy consumption in China. Fisher-Vanden et al. (2016) investigate the determinants of the decline in energy intensity in four Chinese industries – pulp and paper, cement, iron and steel, and aluminum – and find that in all four industries rising energy costs are a significant contributor to the decline in energy intensity over the period 1999-2004. Lin and Zeng (2013) estimate the elasticity of demand for gasoline in China. Cao, Ho and Liang (2016) estimate the income and price elasticities of household energy demand for various energy types using Chinese urban household micro-data collected by the National Bureau of Statistics.

This paper builds upon the existing literature by examining the effects of multiple different energy-related policies in China on energy consumption using province-level data over the period 2002 to 2013. In particular, we collect and construct a novel and comprehensive data set on energy-related policies at the provincial level in China from the 2656 energy-related province-level laws and regulations over the years 2002 to 2013. We construct detailed policy variables for specific types of command and control policies; financial incentives; awards; intellectual property rights; and education and information policies. We analyze the marginal effects of each specific type of energy-related policy on energy consumption, including various forms of fossil fuel consumption and various forms of biomass energy consumption, when also controlling for all other specific types of energy-related policy. Our econometric method employs instruments to address the potential endogeneity of the policies.

According to our results, some types of policies have been effective in reducing energy consumption, including loans to firms for reducing pollution; funding or subsidies for research and development to increase energy efficiency; and providing education and information for energy conservation. However, many other policies have the possibly unintended or even perverse consequence of increasing rather than decreasing energy consumption. These include loans to either firms or households for reducing fossil fuel consumption; emissions standards for air pollution; and intellectual property rights for research and development to increase energy efficiency. Providing education and information for increasing energy efficiency has the perverse effect of leading to a significant increase in electricity consumption per capita and in stalks consumption per capita, possibly due to a rebound effect. Monetary awards for having reduced pollution have different effects on different types of energy consumption.

Our results on the mixed effectiveness of energy-related policies in China in reducing energy consumption have important implications for the design of energy-related policies in China and elsewhere.

The balance of the paper proceeds as follows. Section 3 describes the different types of energy-related policies in China. Section 4 describes our data. Section 5 presents the empirical model. Section 6 presents the results. Section 7 concludes.

2. Energy-Related Policies in China

For our policy variables, we collect and construct a novel and comprehensive data set on energy-related policies at the provincial level in China by collecting data from online databases of laws and regulations from the websites of each of the provincial governments as well as from Lawtime, a website which collects laws and regulations in China ("Lawtime").

Our policy variables are constructed from the 2656 energy-related province-level laws and regulations over the years 2002 to 2013. These province-level laws and regulations include national laws and regulations implemented in each province, some of which may be differentiated by province. Each of the 2656 province-level laws and regulations has multiple clauses, and may include multiple provisions.

For each of the 2656 province-level laws and regulations over the years 2002 to 2013, we categorize their provisions and features into the specific types of command and control policies; financial incentives; awards; intellectual property rights; and education and information policies described below. Because each province-level law and regulation has multiple clauses, provisions, and features each law and regulation may include more than one of the following types of policies.

2.1. Command and control

Our first category of energy-related policies are command and control policies. We categorize the 2656 province-level laws and regulations into whether their features or provisions include policies for the following 7 separate types of command and control policies: (1) an ambient air quality standard for a maximum amount of pollution in air; (2) an ambient water quality standard for a maximum amount of pollution in water; (3) an emissions standard for air pollution for a maximum amount of air pollution emissions; (4) an emissions standard for water pollution for maximum amount of water pollution emissions; (5) a technology standard which requires polluters to use certain technologies, practices, or techniques, such as a certain pollution control technology; (6) a fuel mandate which mandates that a certain share of fuel be renewable, or that the carbon intensity of fuels not exceed a certain amount; and (7) a renewable electricity mandate which mandates that a certain share of electricity be renewable, or that the emissions rate from electricity not exceed a certain amount.

2.2. Financial incentives

Another category of energy-related policies are financial incentives. We consider several types of financial incentives. The first type of financial incentives are favorable tax treatments, which we further delineate into favorable tax treatments for (a) reducing pollution; (b) increasing energy efficiency; or (c) conserving energy.

A second type of financial incentives are environmental taxes, which we further delineate into environmental taxes for (a) water pollution emissions and (b) fossil fuel consumption.

A third type of financial incentives are funding or subsidies, which we further delineate into funding or subsidies for (a) research and development to reduce pollution; (b) research and development to increase energy efficiency; (c) research and development to reduce fossil fuel consumption; (d) research and development to increase renewable energy consumption; (e) reducing pollution; (f) increasing energy efficiency; (g) reducing fossil fuel consumption; and (h) energy conservation.

A third type of financial incentives are loans the government provides to firms, which we further delineate into loans to firms for (a) reducing pollution; (b) increasing energy efficiency; (c) reducing fossil fuel consumption; (d) increasing renewable energy consumption; and (e) energy conservation.

A fourth type of financial incentives are loans provided by the government to households, which we further categorize into loans to households for (a) increasing energy efficiency; (b) reducing fossil fuel consumption; and (c) increasing renewable energy consumption.

2.3. Awards

Another category of energy-related policies are awards that are given after something has been accomplished. We separate awards between monetary awards and non-monetary awards.

For monetary awards, we further distinguish between monetary awards for having (a) reduced pollution; (b) increased energy efficiency; (c) reduced fossil fuel consumption; (d) increased renewable energy consumption; (e) developed technology to reduce pollution; (f) developed technology to increase energy efficiency; (g) developed technology to reduce fossil fuel consumption; (h) developed technology to increase renewable energy consumption; and (i) reduced energy consumption, or saved or conserved energy.

For non-monetary awards, we further distinguish between non-monetary awards for having (a) reduced pollution; (b) increased energy efficiency; (c) reduced fossil fuel consumption; (d) developed technology to reduce pollution; (e) developed technology to reduce fossil fuel consumption; (f) developed technology to increase renewable energy consumption; and (g) reduced energy consumption.

2.4. Intellectual property rights

Another category of energy-related policies are intellectual property rights, which we further categorize into intellectual property rights for (a) research and development to reduce pollution; (b) research and development to increase energy efficiency; (c) research and development to reduce fossil fuel consumption; (d) research and development to increase renewable energy consumption; and (e) other research and development.

2.5. Education and information

Another category of energy-related policies are policies that provide education and information, which we further categorize into policies that provide education and information for (a) reducing pollution; (b) increasing energy efficiency; (c) increasing renewable energy consumption; (d) energy conservation; and (e) managing energy

3. Data

To analyze the effects of energy-related policies in China on energy consumption, we use panel data for 30 provinces from 2002 to 2013. Tibet, Hong Kong, Macau, and Taiwan are excluded from the analysis. Because of missing data prior to 2002, and owing to data limitations for more recent data, we limit the period of study to the period 2002 to 2013.

Data on energy consumption come from the China Energy Statistical Yearbooks. We use data on various forms of fossil fuel energy consumption and various forms of biomass energy consumption. For fossil fuel consumption, we obtain data on the consumption three types of fossil fuels – coal, crude oil, and natural gas – as well as the consumption of four types of fossil fuel distillates – coke, fuel oil, kerosene oil, and diesel oil. We also obtain data on the consumption of gasoline and electricity. For biomass energy consumption, we obtain data on noncommercial energy consumption of biogas, stalks, and firewood in rural areas in China.

Table 1 presents the summary statistics for the energy consumption variables in our data set. We convert the units for each kind of energy consumption into tons coal equivalent (TCE) using conversion factors reported in the China Energy Statistical Yearbook. Table A1 in the Appendix presents the within and between variation for the energy consumption variables. "Within" variation is the variation in the energy consumption variable across years for a given province. "Between" variation is the variation in the energy consumption variable across provinces for a given year.

For our economic variables, we use annual province-level data on the consumer price index for transportation fuels and parts; the consumer price index for residential water, electricity, and fuels; the retail price index for fuels; and GDP per capita from the China Statistical Yearbook. Table 2 presents the summary statistics for the economic variables in our data set.

For our policy variables, we collect and construct a novel data set on energy-related policies at the provincial level in China by collecting data from online databases of laws and regulations from the websites of each of the provincial governments as well as from Lawtime, a website which collects laws and regulations in China ("Lawtime").

Our policy variables are constructed from the 2656 province-level laws and regulations over the years 2002 to 2013. These province-level laws and regulations include national laws and regulations implemented in each province, some of which may be differentiated by province. Each of the 2656 province-level laws and regulations has multiple clauses, and may include multiple provisions.

For each of the 2656 province-level laws and regulations over the years 2002 to 2013, we categorize their provisions and features into the types of policies described in Section 3. Because each province-level law and regulation has multiple clauses, provisions, and features each law and regulation may include more than one type of policy.

For each type of policy, we construct a dummy variable for whether there is a policy of that particular type in province i at time t. It is difficult to quantify the policies along other dimensions, as dimensions such as the stringency of the policy or the extent of the policy are either not observable or difficult to quantify objectively in a single measure, particularly one that aggregates across the 2656 province-level laws and regulations. Moreover, as the focus of this paper is on the marginal effects of different types of energy-related policies when considering and controlling for a full and comprehensive set of all energy-related policies in place, we have opted to use simple measures of each type of policy in favor of being able to include a comprehensive set of many policies. In future work we hope to develop measures to quantify the magnitude and/or stringency of the policies, particularly for the subset of policies we have found in this paper to have significant effects on energy consumption.

We streamline the set of policies we consider by eliminating those policies that have very little variation in our data set, since for these policies we do not have enough variation to identify their effects. First, we drop all policies that were in place in over 90% of the province-years of our data set, since these essentially province-invariant policies are implemented nearly nation-wide and are therefore absorbed in the year effects. This eliminates the policy variable for funding or subsidies for research and development to reduce pollution, which was in place for 97% of the province-years of our data set.

Second, we drop any policy variable that is constant (i.e., always 0 for all years or always 1 for all years) for 28 or more out of the 30 provinces, since these time-invariant policy variables are absorbed by the province fixed effects. This eliminates a number of policy variables, including the policy variable for funding or subsidies for research and development to reduce pollution also excluded because of the first criterion above.

The policy variables that are eliminated because they are always constant for 28 or more out of the 30 provinces include the policy variables for ambient air quality standards; ambient water quality standards; emissions standards for water pollution; fuel mandates; favorable tax treatment for reducing pollution; taxes on water pollution emissions; funding or subsidies for research and development to reduce pollution; funding or subsidies for reducing pollution; funding or subsidies for energy conservation; loans to households for increasing energy efficiency; loans to households for increasing renewable energy consumption; monetary awards for having increased energy efficiency; monetary awards for having developed technology to reduce pollution; monetary awards for having developed technology to reduce fossil fuel consumption; intellectual property rights for research and development to reduce pollution; intellectual property rights for research and development to reduce fossil fuel consumption; intellectual property rights for research and development to increase renewable energy consumption; and intellectual property rights for other research and development.

Tables A2-A7 in the Appendix list, for each of the policy variables we dropped, which provinces always had this type of policy and which provinces never had this type of policy over the 2002-2013 period of our data set.

The policy variables that remain are the following. The command and control policy variables that remain are policy variables for emissions standards for air pollution; technology standards; and renewable electricity mandates.

The tax policy variables that remain are policy variables for favorable tax treatment for increasing energy efficiency; favorable tax treatment for conserving energy; and taxes on fossil fuel consumption.

The funding or subsidies policy variables that remain are policy variables for funding or subsidies for research and development to increase energy efficiency; for research and development to reduce fossil fuel consumption; for research and development to increase renewable energy consumption; for increasing energy efficiency; and for reducing fossil fuel consumption.

The loans policy variables that remain are policy variables for loans to firms for reducing pollution; for increasing energy efficiency; for reducing fossil fuel consumption; for increasing renewable energy consumption; and for energy conservation; and loans to households for reducing fossil fuel consumption.

The monetary awards policy variables that remain are policy variables for monetary awards for having reduced pollution; for having reduced fossil fuel consumption; for having increased renewable energy consumption; for having developed technology to increase energy efficiency; for having developed technology to increase renewable energy consumption; and for having reduced energy consumption, or having saved or conserved energy.

The non-monetary awards policy variables that remain are policy variables for non-monetary awards for having reduced pollution; for having increased energy efficiency; for having reduced fossil fuel consumption; for having developed technology to reduce pollution; for having developed technology to reduce fossil fuel consumption; for having developed technology to increase renewable energy consumption; and for having reduced energy consumption.

The intellectual property rights policy variable that remains is the policy variable for intellectual property rights for research and development to increase energy efficiency.

The education and information policy variables that remain are policy variables for education and information for reducing pollution; for increasing energy efficiency; for increasing renewable energy consumption; for energy conservation; and for managing energy.

Table 3 presents the summary statistics for our policy variables.

4. Econometric Model

To analyze the effects of energy-related policies in China on energy consumption, we estimate the following instrumental variables (IV) fixed effects model with year effects:

$$\ln c_{ijt} = policies_{it}'\beta_1 + \ln economic_{it}'\beta_2 + \alpha_i + \tau_t + \varepsilon_{it},$$

where c_{ijt} is per capita energy consumption for energy type *j* for province *i* in year *t*, $policies_{it}$ is a vector of energy-related policy variables, $economic_{it}$ is a vector of economic variables, α_i is a province fixed effect, τ_t is a year effect, and ε_{it} is an error term.

The types *j* of per capita energy consumption c_{ijt} we analyze include coal consumption, crude oil consumption, natural gas consumption, gasoline consumption, electricity consumption, coke consumption, fuel oil consumption, kerosene consumption, diesel oil consumption, biogas consumption, stalks consumption, and firewood consumption.

The vector $economic_{it}$ of economic variables includes the consumer price index for transportation fuels and parts; the consumer price index for residential water, electricity, and fuels; the retail price index for fuels; and GDP per capita.

The vector $policies_{it}$ of energy-related policy variables includes specific types of command and control policies; financial incentives; awards; intellectual property rights; and education and information policies.

The command and control policy variables include policy variables for emissions standards for air pollution; technology standards; and renewable electricity mandates.

The financial incentives policy variables include policy variables for specific types of taxes; funding or subsidies; loans to firms; and loans to households. The tax policy variables include policy variables for favorable tax treatment for increasing energy efficiency; favorable tax treatment for conserving energy; and taxes on fossil fuel consumption.

The funding or subsidies policy variables include policy variables for funding or subsidies for research and development to increase energy efficiency; for research and development to reduce fossil fuel consumption; for research and development to increase renewable energy consumption; for increasing energy efficiency; and for reducing fossil fuel consumption.

The loans policy variables include policy variables for loans to firms for reducing pollution; for increasing energy efficiency; for reducing fossil fuel consumption; for increasing renewable energy consumption; and for energy conservation; and loans to households for reducing fossil fuel consumption.

The awards policy variables include policy variables for specific types of monetary and non-monetary awards. The monetary awards policy variables include policy variables for monetary awards for having reduced pollution; for having reduced fossil fuel consumption; for having increased renewable energy consumption; for having developed technology to increase energy efficiency; for having developed technology to increase renewable energy consumption; and for having reduced energy consumption, or having saved or conserved energy.

The non-monetary awards policy variables include policy variables for non-monetary awards for having reduced pollution; for having increased energy efficiency; for having reduced fossil fuel consumption; for having developed technology to reduce pollution; for having developed technology to reduce fossil fuel consumption; for having developed technology to increase renewable energy consumption; and for having reduced energy consumption.

The intellectual property rights policy variable is the policy variable for intellectual property rights for research and development to increase energy efficiency.

The education and information policy variables include policy variables for education and information for reducing pollution; for increasing energy efficiency; for increasing renewable energy consumption; for energy conservation; and for managing energy.

For each type of policy, the policy variable for that policy type for province *i* in time *t* is a dummy for whether there is a policy of a particular type in province *i* at time *t*. It is difficult to quantify the policies along other dimensions, as dimensions such as the stringency of the policy or the extent of the policy are either not observable or difficult to quantify objectively in a single measure, particularly one that aggregates across the 2656 province-level laws and regulations. Moreover, as the focus of this paper is on the marginal effects of different types of energy-related policies when considering and controlling for a full and comprehensive set of all energy-related policies in place, we have opted to use simple measures of each type of policy in favor of being able to include a comprehensive set of many policies policies. In future work we hope to develop measures to quantify the magnitude and/or stringency of the policies, particularly for the subset of policies we have found in this paper to have significant effects on energy consumption.

In analyzing the effects of government energy-related policies on energy consumption, one may worry that the policies are endogenous (Rehme, 2011). One reason for this endogeneity is that the presence of certain energy-related policies in certain provinces may be correlated with unobserved factors that affect energy consumption. For example, provinces that have industries such as manufacturing that generate a lot of pollution may have more need for energy-related pollution regulation, but these industries may also consume a lot of energy.

To address any potential endogeneity of the policies, we estimate an instrumental variables (IV) fixed effects model. For each policy type, we instrument for the policy variable for that policy type using the time lagged spatial lag of that policy type in province *i*, which we define as the sum of the policy variables of that policy type over all the other provinces except province *i* at time *t-1*. This instrument is therefore the number of other provinces except province *i* that had that policy type at time *t-1*.

We assume that the time lagged spatial lag of policies in other provinces have no effect on a province's energy consumption except through their effect on the province's current policies. This assumption makes sense since policies of other provinces implemented in the previous year should not influence the energy consumption in that province, except through their effect on the province's current policies. Thus, the instruments are correlated with policies in province *i* at time *t* and do not affect the energy consumption in province *i* at time *t* except through their effect on the policies in province *i* at time *t*.

Table 4 presents the Angrist-Pischke first-stage F-statistics. All the Angrist-Pischke first-stage F-statistics are greater than 8; and 35 out of the 37 Angrist-Pischke first-stage F-statistics are greater than 10.

We choose to use fixed effects instead of random effects because we believe that time-invariant province unobservables are potentially correlated with the regressors; our choice was confirmed by results of Hausman tests in preliminary analyses which deemed fixed effects to be the more appropriate specification (results not shown).

5. Results

Table 5 presents the IV fixed effects results for the consumption of three types of fossil fuels: coal, crude oil, and natural gas. According to the results, emissions standards for air pollution lead to a significant increase of 8.490% in natural gas consumption per capita. Loans to firms for reducing fossil fuel consumption have the perverse effect of leading to a significant increase of 1.186% in crude oil consumption per capita.

Table 6 presents the IV fixed effects results for the consumption of four types of fossil fuel distillates: coke, fuel oil, kerosene oil, and diesel oil. According to the results, loans to firms for reducing pollution have a significant negative effect on coke consumption per capita, decreasing coke consumption per capita by 2.650%. Loans to firms for reducing fossil fuel consumption lead to a significant increase of 2.198% in coke consumption per capita. Loans to households for reducing fossil fuel consumption have the perverse consequence of leading to a significant increase of 8.781% in fuel oil consumption per capita. Monetary awards for having reduced pollution lead to a significant decrease of 2.463% in kerosene oil consumption per capita. Providing education and information for energy conservation leads to a significant decrease of 7.593 % in fuel oil consumption per capita. Higher transportation fuels and parts prices lead to a significant decrease in fuel oil consumption per capita. GDP per capita has a significant positive effect on coke consumption per capita and diesel oil consumption per capita.

Table 7 presents the IV fixed effects results for gasoline and electricity consumption. According to the results, funding or subsidies for research and development to increase energy efficiency lead to a significant decrease of 5.005% in electricity consumption per capita. Loans to firms for reducing fossil fuel consumption have the perverse effect of leading to a significant increase of 0.475% in electricity consumption per capita. Monetary awards for having reduced pollution also lead to a significant increase of 0.384% in electricity consumption per capita. Providing education and information for increasing energy efficiency has the perverse effect of leading to a significant increase of 0.566% in electricity consumption per capita, possibly due to a rebound effect. GDP per capita has a significant positive effect on gasoline consumption per capita.

Table 8 presents the IV fixed effects results for the consumption of three types of biomass energy consumption: biogas, stalks, and firewood. According to the results, funding or subsidies for research and development to increase energy efficiency lead to a significant decrease of 5.055% in stalks consumption per capita. Loans to firms for reducing pollution lead to a significant decrease of 2.685% in biogas consumption per capita. Loans to firms for reducing fossil fuel consumption lead to a significant increase of 2.871% in biogas consumption per capita, 0.475% in stalks consumption per capita, and 1.038% in firewood consumption per capita. Monetary awards for having reduced pollution lead to a significant increase of 0.384% in biogas consumption per capita. Intellectual property rights for research and development to increase energy efficiency lead to a significant increase of 1.873% in stalks consumption per capita. Providing education and information for increasing energy efficiency leads to a significant increase of 0.566% in stalks consumption per capita, possibly due to a rebound effect.

6. Conclusion

This paper examines the effects of energy-related policies in China on energy consumption. In particular, we collect and construct a novel and comprehensive data set on energy-related policies at the provincial level in China from the 2656 energy-related province-level laws and regulations over the years 2002 to 2013. We construct detailed policy variables for specific types of command and control policies; financial incentives; awards; intellectual property rights; and education and information policies.

We analyze the effects of each specific type of policy variable on energy consumption, including various forms of fossil fuel consumption and various forms of biomass energy consumption. We analyze how the different types of energy-related policies affect different types of energy consumption using instruments to address the potential endogeneity of the policies.

According to our results, some types of policies have been effective in reducing energy consumption. Loans to firms for reducing pollution have a significant negative effect on coke consumption per capita, and on biogas consumption per capita. Funding or subsidies for research and development to increase energy efficiency lead to a significant decrease in electricity consumption per capita and in stalks consumption per capita. Providing education and information for energy conservation leads to a significant decrease in fuel oil consumption per capita.

However, many other policies have the possibly unintended or even perverse consequence of increasing rather than decreasing energy consumption. Loans to firms for reducing fossil fuel consumption have the possibly perverse effect of leading to a significant increase in crude oil consumption per capita, in coke consumption per capita, in electricity consumption per capita, in biogas consumption per capita, in stalks consumption per capita, and in firewood consumption per capita. Similarly, loans to households for reducing fossil fuel consumption have the perverse consequence of leading to a significant increase in fuel oil consumption per capita. Emissions standards for air pollution have the perverse effect of leading to a significant increase in natural gas consumption per capita. Intellectual property rights for research and development to increase energy efficiency lead to a significant increase in stalks consumption per capita.

Providing education and information for increasing energy efficiency has the perverse effect of leading to a significant increase in electricity consumption per capita and in stalks consumption per capita, possibly due to a rebound effect.

Some policies have different effects on different types of energy consumption. Monetary awards for having reduced pollution lead to a significant decrease in kerosene oil consumption per capita but a significant increase in electricity consumption per capita.

In terms of the effects of the economic variables on energy consumption, higher transportation fuels and parts prices lead to a significant decrease in fuel oil consumption per capita. GDP per capita has a significant positive effect on gasoline consumption per capita, on coke consumption per capita, and on diesel oil consumption per capita.

In general, there are several possible reasons why some energy-related policies in China may be ineffective or even have perverse consequences. One possible reason is the rebound effect. Energy-related policies may encourage firms or households to increase the efficiency with which they use energy. At first blush it may seem intuitive that improving the efficiency of energy use will lead to a reduction in energy consumption. Evidence from history and empirical research shows, however, that the actual savings in energy consumption from an increase in energy efficiency can be less than the expected savings.

A "rebound" effect arises when some of the gains from improving the efficiency of energy use is lost because of behavioral responses. For example, a decrease in energy consumption due to efficiency improvement also leads to a reduction in the real cost of energy services per unit, and thus brings about an increase in the demand for energy services. Therefore, the potential energy savings and emissions reduction from efficiency improvement might be offset by responses to the cost reduction (Zhang and Lin Lawell, 2017; Gillingham et al., 2013; Lin, Yang and Liu, 2013). Similarly, an increase in energy efficiency can spur economic growth, either through a reallocation of growth through sectoral reallocation or overall growth through an increase in total factor productivity, and the economic growth requires additional energy consumption (Gillingham, Rapson and Wagner, 2016; Zhang and Lin Lawell, 2017).

A rebound effect may at least partially explain our result that providing education and information for increasing energy efficiency has the perverse effect of leading to a significant increase in electricity consumption per capita and in stalks consumption per capita. A rebound effect may also partially explain our result that intellectual property rights for research and development to increase energy efficiency lead to a significant increase in stalks consumption per capita.

A second reason some energy-related policies may be ineffective in reducing energy consumption is that the reduction of energy consumption is not always the primary goal of energy-related policies. For example, the primary objective of energy-related pollution policies may be to reduce pollution rather than to reduce energy consumption *per se*. It is possible that complying with pollution regulations may actually require an increase in energy consumption. For example, our results show that emissions standards for air pollution have the perverse effect of leading to a significant increase in natural gas consumption per capita.

A third reason some energy-related policies might be ineffective in China is that having multiple energy-related policies in place may diminish the effectiveness of the individual policies, or even lead to perverse impacts. In the context of overlapping policies for reducing pollution, Novan (forthcoming) finds that if one policy places a binding cap on a subset of pollutants, additional policies to reduce emissions through expansions in renewable electricity have the potential unintended consequence of increasing instead of decreasing unregulated pollutants. It is possible that a similar perverse impact may occur with some overlapping energy-related policies in China as well.

A fourth reason why some energy-related policies in China may be ineffective or even have perverse consequences is that the structure of energy regulatory agencies in China, where some areas of energy may be regulated by multiple agencies while other areas are not regulated by any, may cause energy-related policies to be ineffective. For renewable energy sources such as wind power, solar power, and bioenergy, coordination problems such as the lack of coordination between projects approved by different levels of government and between renewable power planning and grid planning, have led to a low proportion of grid-connected renewable energy capacity (Zhang et al., 2013). In the meantime, coordination problems among different government sectors may cause inconsistencies in the energy-related policy due to differences in goals. Even within the same government agency, there may be conflicting goals including the desire for importing advanced technology on the one hand, and the desire for protecting the local energy industry in China on the other (Zhang et al, 2009). Therefore, problems in the energy management institutions in China may also lead to the ineffectiveness of energy-related policies. Lin, (2010), Lin Lawell (2017a), and Lin Lawell (2017b) examine the optimal distribution of regulatory power among different tiers of government.

A fifth reason why some energy-related policies in China may be ineffective is that these policies may be poorly enforced and/or have loopholes. Most firms still regard environmental compliance as a burden, leading to conflicts between firms and the government during the enforcement process (Yang and Yao, 2012). Energy-related policies are also poorly enforced on large state-owned power companies, which generate most of the energy power in China (Zhang et al., 2013). Moreover, anecdotally pollution prevention policies in China have loopholes that enable enterprises and some government departments to avoid implementing them (Chen, 2013). Energy-related policies are also plagued by weak monitoring and insufficient legal enforcement resulting from inadequate human and financial resources as well as from bribery (Richerzhagen et al., 2008).

A sixth reason for the ineffectiveness of some energy-related policies is that energy prices in China are often partially controlled by the government. For example, before the 2013 reform in the price of coal for electricity production, there were two different prices for coal: (1) the government-controlled contract price for coal for electricity production, and (2) the market price for coal. When the market price for coal was much higher than its contract price, the coal enterprises were not willing to sell coal to electricity production enterprises and electricity production enterprises ended up suffering from low electricity prices and high coal prices. These problems in this coal-electricity price linkage mechanism have caused electricity shortages in China in recent years (Zhang et al., 2013) and may have caused energy-related policies to be ineffective. When energy prices are partially controlled by the government rather than determined by the market, government policies may be ineffective.

Our results on the mixed effectiveness of energy-related policies in China in reducing energy consumption have important implications for the design of energy-related policies in China and elsewhere.

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Table 1. Summary statistics for energy consumption

	Obs	Mean	Std. Dev.	Min	Max
Coal consumption per capita (tce)	358	2.614	4.031	0.281	55.016
Crude oil consumption per capita (tce)	328	0.530	0.508	0.000005	2.279
Natural gas consumption per capita (tce)	346	0.142	0.170	0.00000003	0.956
Coke consumption per capita (tce)	358	0.225	0.213	0.000002	1.127
Fuel oil consumption per capita (tce)	358	0.050	0.101	0.00001	0.652
Kerosene consumption per capita (tce)	351	0.028	0.061	0.000	0.332
Diesel consumption per capita (tce)	358	0.162	0.092	0.024	0.542
Gasoline consumption per capita (tce)	358	0.095	0.065	0.017	0.324
Electricity consumption per capita (tce)	174	0.121	0.075	0.011	0.536
Biogas consumption per capita (tce)	172	0.003	0.004	0.000003	0.019
Stalks consumption per capita (tce)	174	0.121	0.075	0.011	0.536
Firewood consumption per capita (tce)	170	0.085	0.072	0.0002	0.455

Note: Data are in tons coal equivalent (tce). The data consists of annual province-level data over the period 2002 to 2013.

Table 2. Summary statistics for economic variables

	Obs	Mean	Std. Dev.	Min	Max
Transportation fuels and parts consumer price index	360	105.831	6.293	88.188	117.791
Residential water, electricity, and fuels consumer price index	360	104.595	3.641	92.170	117.566
Fuel retail price index	360	107.648	6.842	85.177	125.076
GDP per capita (yuan) (2002 constant price)	360	2.220	1.557	0.324	7.733

Note: The data consists of annual province-level data over the period 2002 to 2013.

Table 3. Summary statistics for policy variables

	Obs	Mean	Std. Dev.
Command and control			
Emissions standard for air pollution	360	0.783	0.413
Technology standard	360	0.600	0.491
Renewable electricity mandate	360	0.619	0.486
Financial incentives: Taxes			
Favorable tax treatment for increasing energy efficiency	360	0.508	0.501
Favorable tax treatment for conserving energy	360	0.792	0.407
Tax on fossil fuel consumption	360	0.494	0.501
Financial incentives: Funding or subsidies			
For research and development to increase energy efficiency	360	0.381	0.486
For research and development to reduce fossil fuel consumption	360	0.325	0.469
For research and development to increase renewable energy consumption	360	0.394	0.489
For increasing energy efficiency	360	0.494	0.501
For reducing fossil fuel consumption	360	0.439	0.497
Financial incentives: Loans to firms			
For reducing pollution	360	0.367	0.483
For increasing energy efficiency	360	0.531	0.500
For reducing fossil fuel consumption	360	0.572	0.495
For increasing renewable energy consumption	360	0.289	0.454
For energy conservation	360	0.722	0.449

Financial incentives: Loans to households			
For reducing fossil fuel consumption	360	0.447	0.498
Awards: Monetary awards			
For having reduced pollution	360	0.411	0.493
For having reduced fossil fuel consumption	360	0.358	0.480
For having increased renewable energy consumption	360	0.278	0.449
For having developed technology to increase energy efficiency	360	0.244	0.430
For having developed technology to increase renewable energy consumption	360	0.258	0.438
For having reduced energy consumption, or having saved or conserved energy	360	0.572	0.495
Awards: Non-monetary awards			
For having reduced pollution	360	0.475	0.500
For having increased energy efficiency	360	0.406	0.492
For having reduced fossil fuel consumption	360	0.581	0.494
For having developed technology to reduce pollution	360	0.278	0.449
For having developed technology to reduce fossil fuel consumption	360	0.256	0.437
For having developed technology to increase renewable energy consumption	360	0.400	0.491
For having reduced energy consumption	360	0.536	0.499
Intellectual property rights			
For research and development to increase energy efficiency	360	0.300	0.459
Provide education and information			
For reducing pollution	360	0.492	0.501
For increasing energy efficiency	360	0.383	0.487
For increasing renewable energy consumption	360	0.511	0.501

For energy conservation	360	0.422	0.495
For managing energy	360	0.594	0.492

Note: The data consists of annual province-level data over the period 2002 to 2013.

Table 4. Angrist-Pischke First-Stage F-statistics

	Angrist-Pischke First-Stage F-Statistic
Command and control	
Emissions standard for air pollution	34.79
Technology standard	49.00
Renewable electricity mandate	25.54
Financial incentives: Taxes	
Favorable tax treatment for increasing energy efficiency	23.38
Favorable tax treatment for conserving energy	48.60
Tax on fossil fuel consumption	74.07
Financial incentives: Funding or subsidies	
For research and development to increase energy efficiency	38.96
For research and development to reduce fossil fuel consumption	49.31
For research and development to increase renewable energy consumption	54.53
For increasing energy efficiency	15.45
For reducing fossil fuel consumption	94.85
Financial incentives: Loans to firms	
For reducing pollution	91.07
For increasing energy efficiency	118.70
For reducing fossil fuel consumption	46.63
For increasing renewable energy consumption	8.16
For energy conservation	9.93
Financial incentives: Loans to households	
For reducing fossil fuel consumption	50.29
Awards: Monetary awards	
For having reduced pollution	18.89
For having reduced fossil fuel consumption	151.82
For having increased renewable energy consumption	22.34
For having developed technology to increase energy efficiency	247.05
For having developed technology to increase renewable energy consumption	20.86
For having reduced energy consumption, or having saved or conserved energy	30.57
Awards: Non-monetary awards	
For having reduced pollution	97.64
For having increased energy efficiency	61.03
For having reduced fossil fuel consumption	32.43

For having developed technology to reduce pollution	247.24
For having developed technology to reduce fossil fuel consumption	21.79
For having developed technology to increase renewable energy consumption	21.03
For having reduced energy consumption	21.26
Intellectual property rights	
For research and development to increase energy efficiency	135.74
Provide education and information	
For reducing pollution	75.13
For increasing energy efficiency	11.47
For increasing renewable energy consumption	24.89
For energy conservation	14.77
For managing energy	35.96

Note: For each policy variable, we instrument for the policy variable using the time lagged spatial lag of that policy variable in province *i*, which we define as the sum of the values of that policy variable over all the other provinces except province *i* at time *t-1*.

Table 5. Results for fossil fuel consumption

	Dependent variable is:		
	Log coal consumption per capita	*Log crude oil consumption per capita*	*Log natural gas consumption per capita*
	(1)	(2)	(3)
Policy Variables			
Command and control			
Emissions standard for air pollution	-1.147	-1.236	8.490**
	(0.838)	(1.023)	(2.751)
Technology standard	1.975	-0.434	0.932
	(2.288)	(1.304)	(4.686)
Renewable electricity mandate	-0.622	0.457	0.779
	(0.371)	(0.582)	(1.764)
Financial incentives: Taxes			
For increasing energy efficiency	-0.062	-0.635	-2.011
	(0.374)	(1.363)	(1.739)
For conserving energy	-1.732	4.010	-5.260
	(2.337)	(2.368)	(4.720)
Tax on fossil fuel consumption	2.149	0.842	-13.535
	(2.213)	(4.418)	(12.940)
Financial incentives: Funding or subsidies			

For research and development to increase energy efficiency	0.305	1.639	-0.902
	(1.478)	(4.176)	(5.453)
For research and development to reduce fossil fuel consumption	-0.683	-3.406	-0.948
	(1.376)	(4.252)	(5.534)
For research and development to increase renewable energy consumption	1.272	-0.608	0.345
	(0.863)	(0.646)	(4.205)
For increasing energy efficiency	-1.151	1.011	0.596
	(0.778)	(0.651)	(3.579)
For reducing fossil fuel consumption	-3.974	5.890	-6.700
	(2.376)	(4.247)	(8.987)
Financial incentives: Loans to firms			
For reducing pollution	0.045	-1.008	5.480
	(0.860)	(0.736)	(4.070)
For increasing energy efficiency	-1.350	-0.392	2.705
	(0.781)	(1.604)	(3.693)
For reducing fossil fuel consumption	-0.126	1.186*	-5.100
	(0.778)	(0.599)	(3.559)
For increasing renewable energy consumption	-0.655	-0.425	1.852
	(0.452)	(0.415)	(1.757)
For energy conservation	2.775	-2.652	8.542
	(3.236)	(2.571)	(8.246)
Financial incentives: Loans to households			
For reducing fossil fuel consumption	1.130	0.559	7.350
	(1.081)	(1.076)	(4.601)

Awards: Monetary awards			
For having reduced pollution	-0.185	1.577	1.176
	(0.488)	(0.810)	(1.579)
For having reduced fossil fuel consumption	1.871	5.598	-7.458
	(1.952)	(7.895)	(10.085)
For having increased renewable energy consumption	-0.022	-0.775	0.966
	(0.269)	(0.370)	(1.270)
For having developed technology to increase energy efficiency	1.777	-6.014	0.298
	(1.037)	(8.638)	(5.370)
For having developed technology to increase renewable energy consumption	-1.503	3.021	-7.479
	(1.288)	(4.349)	(7.336)
For having reduced energy consumption, or having saved or conserved energy	-0.616	0.382	-3.642
	(1.520)	(2.159)	(7.041)
Awards: Non-monetary awards			
For having reduced pollution	0.110	-2.001	-0.684
	(0.702)	(1.138)	(2.307)
For having increased energy efficiency	0.324	0.737	-1.114
	(0.294)	(0.509)	(1.233)
For having reduced fossil fuel consumption	-0.354	-0.098	9.660
	(0.930)	(0.845)	(13.338)
For having developed technology to reduce pollution	-1.761	0.556	-2.607
	(1.838)	(1.786)	(10.146)
For having developed technology to reduce fossil fuel consumption	-0.800	-0.220	0.961
	(0.449)	(0.387)	(1.092)
For having developed technology to increase renewable energy consumption	2.109	-1.533	4.742
	(1.439)	(4.689)	(7.450)

For having reduced energy consumption	1.296	-0.843	1.495
	(0.972)	(1.243)	(5.140)
Intellectual property rights			
For research and development to increase energy efficiency	0.953	2.406	2.488
	(2.820)	(2.751)	(14.446)
Provide education and information			
For reducing pollution	-1.332	-1.013	7.427
	(0.770)	(2.803)	(4.609)
For increasing energy efficiency	0.334	-0.313	0.230
	(0.443)	(0.376)	(1.490)
For increasing renewable energy consumption	0.187	-0.224	1.090
	(0.317)	(0.425)	(1.879)
For energy conservation	-0.591	0.401	-2.658
	(0.823)	(0.405)	(3.880)
For managing energy	1.269	0.564	-7.571
	(1.279)	(1.965)	(5.695)
Economic Variables			
Log transportation fuels and parts consumer price index	-0.428	-1.704	-36.715
	(4.390)	(6.067)	(28.380)
Log residential water, electricity, and fuels consumer price index	6.563	12.859	-11.537
	(8.481)	(7.827)	(26.961)
Log fuel retail price index	0.624	-2.628	43.339

	(6.108)	(7.172)	(37.318)
Log GDP per capita (yuan) (2002 constant price)	1.070	-0.388	-0.077
	(0.434)	(0.456)	(1.753)
Province fixed effects	Y	Y	Y
Year effects	Y	Y	Y
Observations	330	303	325
R-squared	0.1915	0.1223	-0.4614

Notes: Robust standard errors in parentheses. For each policy variable, we instrument for the policy variable using the time lagged spatial lag of that policy variable in province *i*, which we define as the sum of the values of that policy variable over all the other provinces except province *i* at time *t-1*. Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

Table 6. Results for fossil fuel distillates

	Dependent variable is:			
	Log coke consumption per capita	*Log fuel oil consumption per capita*	*Log kerosene oil consumption per capita*	*Log diesel oil consumption per capita*
	(6)	(7)	(8)	(9)
Policy Variables				
Command and control				
Emissions standard for air pollution	-0.005	-1.541	-1.701	-0.377
	(1.065)	(2.068)	(1.504)	(0.412)
Technology standard	-1.760	1.045	-0.424	0.077
	(2.459)	(3.985)	(1.942)	(0.789)
Renewable electricity mandate	-0.298	1.552	0.961	-0.246
	(0.527)	(1.387)	(0.949)	(0.153)
Financial incentives: Taxes				
Favorable tax treatment for increasing energy efficiency	0.853	0.669	-0.973	0.140
	(0.557)	(1.259)	(0.704)	(0.169)
Favorable tax treatment for conserving energy	1.015	0.022	0.724	0.532
	(2.206)	(3.691)	(1.508)	(0.713)
Tax on fossil fuel consumption	1.924	4.986	-0.361	-0.377
	(2.594)	(6.292)	(4.441)	(0.894)
Financial incentives: Funding or subsidies				

For research and development to increase energy efficiency	-1.593	3.045	-2.051	-0.848
	(1.387)	(4.599)	(3.311)	(0.612)
For research and development to reduce fossil fuel consumption	0.274	-6.645	1.419	1.019
	(1.403)	(4.528)	(2.948)	(0.632)
For research and development to increase renewable energy consumption	0.752	5.968	0.588	0.176
	(0.826)	(3.246)	(1.896)	(0.367)
For increasing energy efficiency	0.844	-3.210	0.343	0.026
	(0.921)	(2.742)	(1.879)	(0.353)
For reducing fossil fuel consumption	-1.474	-10.857	1.006	0.956
	(2.549)	(6.603)	(5.379)	(0.964)
Financial incentives: Loans to firms				
For reducing pollution	-2.650*	5.160	2.919	-0.155
	(1.269)	(3.162)	(2.141)	(0.349)
For increasing energy efficiency	-0.599	-1.372	2.105	-0.156
	(0.748)	(1.984)	(1.323)	(0.355)
For reducing fossil fuel consumption	2.198*	-5.334	-2.079	-0.168
	(1.104)	(3.136)	(2.101)	(0.308)
For increasing renewable energy consumption	0.162	-0.070	-0.131	-0.194
	(0.527)	(0.969)	(0.651)	(0.270)
For energy conservation	-1.536	0.560	0.483	-0.063
	(3.419)	(5.733)	(3.048)	(1.091)
Financial incentives: Loans to households				
For reducing fossil fuel consumption	-0.545	8.781*	1.728	-0.115
	(1.342)	(4.239)	(2.721)	(0.459)

Awards: Monetary awards				
For having reduced pollution	-0.100	0.931	-2.463*	-0.239
	(0.414)	(1.635)	(1.051)	(0.246)
For having reduced fossil fuel consumption	-1.425	8.716	-3.130	-0.886
	(2.026)	(6.402)	(4.912)	(0.863)
For having increased renewable energy consumption	0.229	0.238	0.497	-0.160
	(0.252)	(0.960)	(0.870)	(0.147)
For having developed technology to increase energy efficiency	1.736	7.080	2.868	0.220
	(1.285)	(4.241)	(2.330)	(0.437)
For having developed technology to increase renewable energy consumption	-0.149	-4.411	1.422	0.193
	(1.180)	(4.038)	(2.743)	(0.594)
For having reduced energy consumption, or having saved or conserved energy	0.840	-4.415	2.678	0.646
	(1.253)	(4.079)	(2.849)	(0.623)
Awards: Non-monetary awards				
For having reduced pollution	0.570	-1.416	1.494	0.270
	(0.666)	(2.072)	(1.298)	(0.292)
For having increased energy efficiency	0.392	0.903	-0.022	0.113
	(0.296)	(1.243)	(0.921)	(0.183)
For having reduced fossil fuel consumption	0.099	1.229	-3.355	-0.034
	(1.023)	(2.324)	(2.700)	(0.475)
For having developed technology to reduce pollution	0.424	-10.795	-1.929	0.431
	(1.999)	(6.674)	(4.387)	(0.825)
For having developed technology to reduce fossil fuel consumption	0.535	-0.429	0.515	-0.139
	(0.413)	(0.652)	(0.364)	(0.132)
For having developed technology to increase renewable energy consumption	0.491	6.011	-1.573	-0.392
	(1.306)	(4.542)	(2.883)	(0.594)

For having reduced energy consumption	-0.414	4.750	-2.991	-0.079
	(1.048)	(3.433)	(2.266)	(0.503)
Intellectual property rights				
For research and development to increase energy efficiency	-2.211	11.176	-3.812	-1.407
	(2.854)	(9.170)	(5.769)	(1.088)
Provide education and information				
For reducing pollution	-0.612	-2.121	-1.096	-0.418
	(0.972)	(2.386)	(1.931)	(0.355)
For increasing energy efficiency	-0.681	0.099	0.539	0.206
	(0.558)	(0.705)	(0.434)	(0.177)
For increasing renewable energy consumption	0.330	-0.189	-0.404	-0.051
	(0.378)	(1.146)	(0.877)	(0.153)
For energy conservation	-1.281	-7.593*	-1.969	-0.030
	(0.855)	(3.518)	(1.691)	(0.337)
For managing energy	0.620	1.109	0.671	0.355
	(1.166)	(3.350)	(2.517)	(0.436)
Economic Variables				
Log transportation fuels and parts consumer price index	3.795	-29.193*	6.756	0.547
	(6.569)	(13.757)	(9.694)	(2.467)
Log residential water, electricity, and fuels consumer price index	2.792	-7.978	2.399	0.384
	(8.367)	(16.832)	(11.287)	(3.301)
Log fuel retail price index	-6.283	31.545	-8.339	-1.913

	(7.390)	(17.655)	(14.662)	(3.064)
Log GDP per capita (yuan) (2002 constant price)	1.917*	-0.353	0.049	1.273***
	(0.753)	(1.625)	(0.961)	(0.180)
Province fixed effects	Y	Y	Y	Y
Year effects	Y	Y	Y	Y
Observations	330	330	322	330
R-squared	0.2136	-1.6641	-0.2666	0.7603

Notes: Robust standard errors in parentheses. For each policy variable, we instrument for the policy variable using the time lagged spatial lag of that policy variable in province *i*, which we define as the sum of the values of that policy variable over all the other provinces except province *i* at time *t-1*. Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

Table 7. Results for gasoline and electricity consumption

	Dependent variable is:	
	Log gasoline consumption per capita	*Log electricity consumption per capita*
	(4)	(5)
Policy Variables		
Command and control		
Emissions standard for air pollution	-0.284	0.251
	(0.332)	(0.314)
Technology standard	-0.206	-0.046
	(0.574)	(0.281)
Renewable electricity mandate	-0.292	0.378
	(0.210)	(0.283)
Financial incentives: Taxes		
Favorable tax treatment for increasing energy efficiency	0.052	-0.305
	(0.188)	(0.673)
Favorable tax treatment for conserving energy	0.556	1.890
	(0.603)	(1.100)
Tax on fossil fuel consumption	0.609	-3.583
	(1.085)	(1.871)
Financial incentives: Funding or subsidies		
For research and development to increase energy efficiency	0.385	-5.005**

	(0.623)	(1.722)
For research and development to reduce fossil fuel consumption	0.144	4.198
	(0.536)	(1.771)
For research and development to increase renewable energy consumption	-0.198	0.088
	(0.462)	(0.340)
For increasing energy efficiency	-0.056	0.372
	(0.347)	(0.631)
For reducing fossil fuel consumption	0.398	1.107
	(0.772)	(1.561)
Financial incentives: Loans to firms		
For reducing pollution	0.128	-0.261
	(0.461)	(0.328)
For increasing energy efficiency	-0.256	0.630
	(0.362)	(0.620)
For reducing fossil fuel consumption	-0.549	0.475*
	(0.339)	(0.228)
For increasing renewable energy consumption	-0.059	0.144
	(0.230)	(0.133)
For energy conservation	-0.464	-1.791
	(0.962)	(1.218)
Financial incentives: Loans to households		
For reducing fossil fuel consumption	0.061	
	(0.548)	
Awards: Monetary awards		

For having reduced pollution	-0.122	0.384*
	(0.292)	(0.182)
For having reduced fossil fuel consumption	0.812	-1.535
	(1.068)	(1.279)
For having increased renewable energy consumption	-0.149	-0.233
	(0.172)	(0.261)
For having developed technology to increase energy efficiency	0.279	-1.480
	(0.605)	(1.607)
For having developed technology to increase renewable energy consumption	0.570	0.248
	(0.497)	(0.442)
For having reduced energy consumption, or having saved or conserved energy	-0.546	0.137
	(0.727)	(0.500)
Awards: Non-monetary awards		
For having reduced pollution	-0.025	
	(0.272)	
For having increased energy efficiency	-0.390	0.278
	(0.229)	(0.443)
For having reduced fossil fuel consumption	0.019	2.126
	(0.436)	(1.371)
For having developed technology to reduce pollution	-1.047	
	(1.005)	
For having developed technology to reduce fossil fuel consumption	0.107	0.020
	(0.106)	(0.230)
For having developed technology to increase renewable energy consumption	-0.245	
	(0.533)	
For having reduced energy consumption	0.211	0.029

	(0.484)	(0.366)
Intellectual property rights		
For research and development to increase energy efficiency	1.364	1.873
	(1.374)	(0.940)
Provide education and information		
For reducing pollution	-0.173	-0.066
	(0.472)	(0.420)
For increasing energy efficiency	0.044	0.566*
	(0.136)	(0.231)
For increasing renewable energy consumption	0.231	0.139
	(0.191)	(0.175)
For energy conservation	-0.627	-0.025
	(0.503)	(0.206)
For managing energy	0.774	
	(0.659)	
<ins>Economic Variables</ins>		
Log transportation fuels and parts consumer price index	0.994	4.342
	(2.479)	(5.259)
Log residential water, electricity, and fuels consumer price index	-0.891	1.563
	(2.425)	(4.100)
Log fuel retail price index	-2.689	1.841
	(2.925)	(2.882)

Log GDP per capita (yuan) (2002 constant price)	0.776***	1.150
	(0.235)	(1.014)
Province fixed effects	Y	Y
Year effects	Y	Y
Observations	330	145
R-squared	0.5562	0.2837

Notes: Robust standard errors in parentheses. For each policy variable, we instrument for the policy variable using the time lagged spatial lag of that policy variable in province *i*, which we define as the sum of the values of that policy variable over all the other provinces except province *i* at time *t-1*. For the electricity consumption regression, the policy variables for loans to households for reducing pollution; non-monetary awards for having reduced pollution; non-monetary awards for having developed technology to reduce pollution; having developed technology to increase renewable energy consumption; and education and information for managing energy are dropped owing to collinearity in the smaller sample size of data available for electricity consumption. Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

Table 8. Results for biomass energy consumption

	Dependent variable is:		
	Log biogas consumption per capita	*Log stalks consumption per capita*	*Log firewood consumption per capita*
	(10)	(11)	(12)
Policy Variables			
Command and control			
Emissions standard for air pollution	-0.500	0.251	-0.592
	(0.465)	(0.314)	(0.485)
Technology standard	-0.620	-0.046	-0.628
	(0.760)	(0.281)	(0.438)
Renewable electricity mandate	-1.443	0.378	0.135
	(1.160)	(0.283)	(0.598)
Financial incentives: Taxes			
Favorable tax treatment for increasing energy efficiency	-1.295	-0.305	-0.687
	(0.998)	(0.673)	(0.734)
Favorable tax treatment for conserving energy	2.480	1.890	0.476
	(1.549)	(1.100)	(1.064)
Tax on fossil fuel consumption	0.750	-3.583	0.421
	(2.470)	(1.871)	(1.756)
Financial incentives: Funding or subsidies			

For research and development to increase energy efficiency	-2.950	-5.005**	-4.714
	(4.350)	(1.722)	(2.571)
For research and development to reduce fossil fuel consumption	-0.402	4.198	3.994
	(4.424)	(1.771)	(2.615)
For research and development to increase renewable energy consumption	1.504	0.088	0.283
	(0.824)	(0.340)	(0.381)
For increasing energy efficiency	2.961	0.372	1.743
	(2.785)	(0.631)	(1.498)
For reducing fossil fuel consumption	1.186	1.107	-2.034
	(1.921)	(1.561)	(1.980)
Financial incentives: Loans to firms			
For reducing pollution	-2.685**	-0.261	-0.895
	(0.934)	(0.328)	(0.517)
For increasing energy efficiency	0.934	0.630	0.103
	(0.789)	(0.620)	(0.532)
For reducing fossil fuel consumption	2.871**	0.475*	1.038*
	(0.921)	(0.228)	(0.446)
For increasing renewable energy consumption	0.019	0.144	0.316
	(0.363)	(0.133)	(0.276)
For energy conservation	-2.216	-1.791	-0.464
	(1.691)	(1.218)	(1.169)
Awards: Monetary awards			
For having reduced pollution	0.186	0.384*	0.300
	(0.497)	(0.182)	(0.321)
For having reduced fossil fuel consumption	2.311	-1.535	0.634

	(3.472)	(1.279)	(2.267)
For having increased renewable energy consumption	0.683	-0.233	-0.955
	(0.736)	(0.261)	(0.527)
For having developed technology to increase energy efficiency	-4.476	-1.480	0.526
	(3.948)	(1.607)	(2.377)
For having developed technology to increase renewable energy consumption	1.515	0.248	-0.855
	(1.640)	(0.442)	(0.944)
For having reduced energy consumption, or having saved or conserved energy	0.344	0.137	-0.057
	(0.971)	(0.500)	(0.601)
Awards: Non-monetary awards			
For having increased energy efficiency	-0.036	0.278	0.355
	(0.561)	(0.443)	(0.604)
For having reduced fossil fuel consumption	0.333	2.126	1.384
	(0.863)	(1.371)	(0.869)
For having developed technology to reduce fossil fuel consumption	-0.476	0.020	-0.905
	(0.409)	(0.230)	(0.666)
For having reduced energy consumption	0.262	0.029	0.590
	(0.693)	(0.366)	(0.467)
Intellectual property rights			
For research and development to increase energy efficiency	1.941	1.873*	0.000
	(1.416)	(0.940)	(0.900)
Provide education and information			
For reducing pollution	-0.464	-0.066	0.298
	(0.948)	(0.420)	(0.621)

For increasing energy efficiency	-0.177	0.566*	-0.221
	(0.382)	(0.231)	(0.370)
For increasing renewable energy consumption	0.575	0.139	0.083
	(0.480)	(0.175)	(0.203)
For energy conservation	-0.705	-0.025	0.190
	(0.679)	(0.206)	(0.246)
Economic Variables			
Log transportation fuels and parts consumer price index	-17.714	4.342	-7.787
	(12.272)	(5.259)	(7.649)
Log residential water, electricity, and fuels consumer price index	-7.781	1.563	-6.868
	(7.200)	(4.100)	(6.547)
Log fuel retail price index	4.500	1.841	1.387
	(4.983)	(2.882)	(3.087)
Log GDP per capita (yuan) (2002 constant price)	2.501	1.150	-1.009
	(3.137)	(1.014)	(2.334)
Province fixed effects	Y	Y	Y
Year effects	Y	Y	Y
Observations	143	145	142
R-squared	0.5607	0.2837	0.1160

Notes: Robust standard errors in parentheses. For each policy variable, we instrument for the policy variable using the time lagged spatial lag of that policy variable in province *i*, which we define as the sum of the values of that policy variable over all the other provinces except province *i* at time *t-1*. Policy variables for loans to households for reducing pollution; non-monetary awards for having reduced pollution; non-monetary awards for having developed technology to reduce pollution; having developed technology to increase renewable energy consumption; and education and information for managing energy are dropped owing to collinearity in the smaller sample size of data available for biomass energy consumption. Significance codes: * 5% level, ** 1% level, and *** 0.1% level.

Appendix

Table A1. Within and between variation for energy consumption

		Mean	Std. Dev.	Min	Max	# Obs
Coal consumption per capita (tce)	overall	2.614	4.031	0.281	55.016	358
	between		2.223	0.556	10.590	
	within		3.389	-4.066	47.039	
Crude oil consumption per capita (tce)	overall	0.530	0.508	0.000	2.279	328
	between		0.485	0.000	1.919	
	within		0.177	-0.374	1.105	
Natural gas consumption per capita (tce)	overall	0.142	0.170	0.000	0.956	346
	between		0.153	0.005	0.585	
	within		0.078	-0.160	0.513	
Coke consumption per capita (tce)	overall	0.225	0.213	0.000	1.127	358
	between		0.188	0.009	0.771	
	within		0.105	-0.285	0.581	
Fuel oil consumption per capita (tce)	overall	0.050	0.101	0.000	0.652	358
	between		0.097	0.002	0.515	
	within		0.031	-0.108	0.251	
Kerosene consumption per capita (tce)	overall	0.028	0.061	0.000	0.332	351
	between		0.059	0.001	0.244	
	within		0.018	-0.091	0.116	
Diesel consumption per capita (tce)	overall	0.162	0.092	0.024	0.542	358
	between		0.073	0.071	0.340	
	within		0.057	-0.111	0.371	
Gasoline consumption per capita (tce)	overall	0.095	0.065	0.017	0.324	358
	between		0.057	0.034	0.254	
	within		0.031	-0.004	0.201	

Electricity consumption per capita (tce)	overall	0.121	0.075	0.011	0.536	174
	between		0.063	0.022	0.268	
	within		0.042	0.039	0.462	
Biogas consumption per capita (tce)	overall	0.003	0.004	0.000	0.019	172
	between		0.004	0.000	0.014	
	within		0.002	-0.002	0.010	
Stalks consumption per capita (tce)	overall	0.121	0.075	0.011	0.536	174
	between		0.063	0.022	0.268	
	within		0.042	0.039	0.462	
Firewood consumption per capita (tce)	overall	0.085	0.072	0.000	0.455	170
	between		0.062	0.008	0.268	
	within		0.040	-0.103	0.318	

Notes: "Within" variation is the variation in the energy consumption variable across years for a given province. "Between" variation is the variation in the energy consumption variable across provinces for a given year.

Table A2. Command and control policy variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Command and control			
	Ambient air quality standard	Ambient water quality standard	Emissions standard for water pollution	Fuel mandate
Anhui	1	1	1	1
Beijing	1	1	1	
Chongqing	1	1		
Fujian	1	1	1	1
Gansu	0	0	1	1
Guangdong	1	1	1	1
Guangxi	1	1	1	1
Guizhou	0	0	1	1
Hainan	1	1	1	1
Hebei	1	1	1	0
Heilongjiang		0	0	0
Henan	1	1	1	1
Hubei	1	1	1	1
Hunan	1	1	1	1
Inner Mongolia	0	0	0	0
Jiangsu	1	1	1	1
Jiangxi	1	1	1	0
Jilin	0	0	1	0
Liaoning	1	1	1	0

Ningxia	0	0	0	1
Qinghai	0	0	0	1
Shaanxi	0	0	1	1
Shandong	1	1	1	1
Shanghai	1	1	1	1
Shanxi				0
Sichuan	1	1	1	1
Tianjin	1	1	1	1
Xinjiang	0	0	1	1
Yunnan	0	0	0	1
Zhejiang	1	1	1	1

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell.

Table A3. Tax variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Financial incentives: Taxes	
	Favorable tax treatment for reducing pollution	Tax on water pollution emissions
Anhui	0	0
Beijing	0	0
Chongqing	0	0
Fujian	0	0
Gansu	0	1
Guangdong	1	1
Guangxi	1	0
Guizhou	0	1
Hainan	1	0
Hebei	0	0
Heilongjiang	0	0
Henan	1	1
Hubei	1	0
Hunan	0	0
Inner Mongolia	0	0
Jiangsu	0	0
Jiangxi	1	0
Jilin	0	0
Liaoning	1	0
Ningxia	0	1
Qinghai	0	1
Shaanxi	0	1
Shandong	1	1
Shanghai	1	0
Shanxi	0	0
Sichuan	1	0
Tianjin	1	
Xinjiang	0	1
Yunnan		1
Zhejiang	1	0

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell

Table A4. Funding or subsidies policy variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Financial incentives: Funding or subsidies		
	For research and development to reduce pollution	For reducing pollution	For energy conservation
Anhui	1	1	1
Beijing	1	1	1
Chongqing	1	0	1
Fujian	1	1	1
Gansu	1	0	0
Guangdong	1	1	1
Guangxi	1	1	1
Guizhou	1	1	0
Hainan	1	1	1
Hebei	1		0
Heilongjiang	1	0	0
Henan	1	1	1
Hubei	1	0	0
Hunan	1	0	0
Inner Mongolia	0	0	0
Jiangsu	1	1	1
Jiangxi	1	0	0
Jilin	1	0	0
Liaoning	1	0	0

Ningxia	1	0	0
Qinghai	1	0	0
Shaanxi	1	0	0
Shandong	1	1	1
Shanghai	1		
Shanxi	1	0	
Sichuan	1		1
Tianjin	1	1	1
Xinjiang	1	0	0
Yunnan	1	0	0
Zhejiang	1	0	0

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell.

Table A5. Loans to households policy variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Financial incentives: Loans to households	
	For increasing energy efficiency	For increasing renewable energy consumption
Anhui	0	0
Beijing		0
Chongqing	0	0
Fujian	0	0
Gansu	1	0
Guangdong	1	1
Guangxi	1	1
Guizhou	1	0
Hainan		
Hebei	0	0
Heilongjiang	0	0
Henan	1	1
Hubei	0	0
Hunan	0	1
Inner Mongolia	0	0
Jiangsu	0	0
Jiangxi	0	0
Jilin	0	0
Liaoning	0	1
Ningxia	0	0

Qinghai	0	0
Shaanxi	0	0
Shandong	1	1
Shanghai	0	0
Shanxi	0	0
Sichuan	0	1
Tianjin	0	0
Xinjiang	0	0
Yunnan	1	0
Zhejiang	0	0

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell.

Table A6. Monetary awards policy variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Awards: Monetary awards		
	For having increased energy efficiency	For having developed technology to reduce pollution	For having developed technology to reduce fossil fuel consumption
Anhui	0	0	0
Beijing	0	0	0
Chongqing	0	1	0
Fujian	1	0	
Gansu	0	0	0
Guangdong	1	1	1
Guangxi		0	0
Guizhou	0	0	0
Hainan		0	0
Hebei	0	0	0
Heilongjiang	0	0	0
Henan	1	0	0
Hubei	0	0	0
Hunan	1	0	0
Inner Mongolia	0	0	0
Jiangsu	0	0	0
Jiangxi	0		0
Jilin	0	0	0
Liaoning	0	0	0

Ningxia	0	0	0
Qinghai	0	0	0
Shaanxi	0	0	0
Shandong	1	1	1
Shanghai	1	1	0
Shanxi	1	0	0
Sichuan	1	1	1
Tianjin	1		
Xinjiang	0	0	0
Yunnan	0	0	0
Zhejiang	1	1	0

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell.

Table A7. Intellectual property rights policy variables that we dropped from the empirical analysis because they constant for at least 28 out of the 30 provinces

	Intellectual property rights for research and development to:			
	Reduce pollution	Reduce fossil fuel consumption	Increase renewable energy consumption	Other
Anhui	1	1	1	1
Beijing	1	1	1	1
Chongqing	1	0	0	1
Fujian	1	1	1	1
Gansu	0	1	0	1
Guangdong	1	1	1	0
Guangxi	1	1	0	0
Guizhou	0	1	0	0
Hainan		1	1	0
Hebei	0	0	0	0
Heilongjiang	0	0	0	1
Henan	1	1	1	1
Hubei	0	0	0	0
Hunan	0	0	0	0
Inner Mongolia	1	0	0	0
Jiangsu		1	1	1
Jiangxi	0	0	1	
Jilin	0	0		1
Liaoning	0	0	0	1

Ningxia	0	1	0	0
Qinghai	0	1	0	
Shaanxi	1	1	0	1
Shandong		1	1	1
Shanghai	0	1	0	0
Shanxi	1	0	0	1
Sichuan	0	0	1	1
Tianjin	1			1
Xinjiang	0	1	0	1
Yunnan	0	1	0	1
Zhejiang	0	1	0	0

Notes: For each type of policy, provinces that have that type of policy for every year during the 2002-2013 period are indicated with "1"; provinces that never have that type of policy for any year during the 2002-2013 period are indicated with "0"; and provinces that have that type of policy for some years but not others during the 2002-2013 period are indicated with a blank cell.