The effects of China's biofuel policies on agricultural and ethanol markets[1]

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Abstract

This paper examines the effects of the E10 ethanol-blend policy and the ethanol production subsidy in China on ethanol supply, ethanol plant entry, ethanol prices, corn production, wheat production, cassava production, crop prices, and gasoline prices. We use instrumental variables to address the endogeneity of prices in our econometric models of ethanol supply, ethanol plant investment, and feedstock crop production. We use vector autoregression models and Granger causality tests to examine the relationships among ethanol price, corn price, gasoline price, the E10 ethanol-blend policy, and the ethanol production subsidy. Our results indicate that the E10 ethanol-blend policy has a positive effect on ethanol supply, ethanol plant entry, and corn production, but no significant effect on the supply elasticity, wheat production, or cassava production. When the E10 ethanol-blend policy is in place, ethanol price has a net negative effect on ethanol plant entry. The production subsidy has a negative effect on wheat production and cassava production, but no significant effect on ethanol supply or ethanol plant entry. We also find that ethanol policies such as the E10 policy and the ethanol subsidy can Granger-cause feedstock price and gasoline price, but generally does not Granger-cause ethanol price. The ethanol price Granger-causes feedstock prices and gasoline price. Feedstock prices Granger-cause each other.

Keywords: ethanol, China, feedstocks
***JEL* codes:** Q16, Q48, Q42

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1. Introduction

International attention has emerged in support of the development and use of ethanol. The motivating factors for this attention and support include high oil prices, security concerns from relying on foreign energy sources, support for economic growth in the agricultural community, the use of surplus grains, environmental goals related to criteria pollutants, and climate change emissions.

However, the effects of these biofuel policies on land use, water use, agricultural markets, ethanol markets, and gasoline markets are unclear. For example, because the feedstocks used for the production of ethanol, specifically first generation biofuel, can also be used for food, there is a concern that ethanol policies might affect the relationship between food and fuel markets (Chen and Khanna, 2012), and, in particular, have potential adverse effects on the price of basic food prices for the world's poor (Runge and Senauer, 2007; Rajagopal et al., 2007; Wright, 2014; Poudel et al., 2012; Abbott, Hurt and Tyner, 2008, 2009, 2011; de Gorter, Drabik and Just, 2013; de Gorter et al., 2013).

The development and use of alternative sources of transportation energy are particularly important in China, a country that is experiencing rapid economic growth and, along with it, rapid growth in vehicle ownership and gasoline consumption. The International Energy Agency (2014) estimates that half of the world oil demand growth till 2035 is likely to come from China overtaking the U.S. as the world's biggest oil consumer. The rapid growth in vehicle ownership and gasoline consumption associated with urbanization is linked to increasing global warming, emissions, air pollution and other problems. In 2011, China's CO_2 emissions constituted 29 percent of world CO_2 emissions (EDGAR, 2014).

China began producing fuel ethanol in the early 2000s. Corn ethanol is the main source of ethanol production in China, accounting for 64 percent of the total ethanol production. China produced 340 million gallons of ethanol in 2012. Nearly 20% of gasoline consumed in China is blended with 10% ethanol which utilizes 0.71% of country's total grain production. Other feedstocks used for ethanol production in China are wheat and cassava. In 2014, the production of fuel ethanol in China was only 1.83 percent of total gasoline consumption (USDA FAS, 2014). China is currently the third largest producer of ethanol in the world, behind Brazil and the United States.

China has implemented policies at both the national and provincial level to support the development and use of fuel ethanol. At the provincial level, several provinces in China have imposed an E10 ethanol-blend mandate. E10 is a fuel mixture of 10% ethanol and 90% gasoline that can be used in the internal combustion engines of most modern automobiles and light-duty vehicles. An E10 ethanol-blend mandate mandates an E10 ethanol blend. Table 1a lists the provinces that have implemented an E10 ethanol-blend policy along with the dates when each province implemented the policy.

In addition to the E10 ethanol-blend policy in some provinces, the national Chinese government has also implemented a fuel-ethanol production subsidy. Table 1b presents the level of the national fuel-ethanol production subsidy over time.

In this paper, we examine the effects of China's biofuel policies on agricultural markets and the ethanol market in China. In particular, we use econometric analyses to examine the effects of the E10 policy and the ethanol production subsidy in China on ethanol supply, ethanol plant entry, ethanol prices, corn production, wheat production, cassava production, crop prices, and gasoline prices. We use instrumental variables to address the endogeneity of prices in our econometric models of ethanol supply, ethanol plant investment, and feedstock crop production.

We use vector autoregression models and Granger causality tests to examine the relationships among ethanol price, corn price, gasoline price, the E10 ethanol-blend policy, and the ethanol production subsidy.

Our results indicate that the E10 ethanol-blend policy has a positive effect on ethanol supply, ethanol plant entry, and corn production, but no significant effect on the supply elasticity, wheat production, or cassava production. When the E10 ethanol-blend policy is in place, ethanol price has a net negative effect on ethanol plant entry. The production subsidy has a negative effect on wheat production and cassava production, but no significant effect on ethanol supply or ethanol plant entry.

We also find that ethanol policies such as the E10 policy and the ethanol subsidy can Granger-cause feedstock price and gasoline price, but generally does not Granger-cause ethanol price. The ethanol price Granger-causes feedstock prices and gasoline price. Feedstock prices Granger-cause each other, consistent with a law of one price for crops that arises because crops compete with each other for land (de Gorter, Drabik and Just, 2015).

The balance of our paper proceeds as follows. We review the previous literature in Section 2. We describe our methods in Section 3 and our data in Section 4. We present our results in Section 5. Section 6 concludes.

2. Previous Literature

We build on several strands of existing literature. Our model of ethanol supply builds upon previous work analyzing the effects of government policies on the ethanol industry in the United States (Cotti and Skidmore; Schmit, Luo and Tauer, 2009; Schmit, Luo and Conrad, 2011; Babcock, 2011; Babcock, 2013; Bielen, Newell and Pizer, 2016; Yi, Lin Lawell and Thome, 2016;

Thome and Lin Lawell, 2017), Thailand (Herath Mudiyanselage, Lin Lawell and Yi, 2013), Europe (Yi and Lin Lawell, 2016), and Canada (Yi and Lin Lawell, 2017).

Our model of the relationships among ethanol price, corn price, gasoline price, the E10 ethanol-blend policy, and the ethanol production subsidy relates to the literature on the relationship between ethanol policies and food and/or ethanol prices. De Gorter, Drabik and Just (2015) combine theory and empirical evidence on how biofuel policies create a link between crop (food grains and oilseeds) and biofuel (ethanol and biodiesel) prices. Chen and Khanna (2012) examine the effect of biofuel policies on food prices in the U.S. Maniloff and Lee (2015) examine the impact of the United States ethanol mandate on food price volatility. Drabik, Ciaian and Pokrivčák (2016) examine the effect of ethanol policies on vertical price transmission in corn and food markets. Lade, Lin Lawell and Smith (2016) examine the effects of U.S. ethanol policy shocks on abnormal returns in crude oil, ethanol, soybean oil, corn, and sugar futures contracts. Baumeister, Ellwanger and Kilian (2016) examine the effect of the U.S. Renewable Fuel Standard on market expectations of the price of ethanol.

Our analysis of the effects of ethanol policies on crop production and on crop prices builds on the previous literature on the relationship between food and fuel markets. One strand of this literature examines the potential adverse effects of ethanol on the price of basic food prices for the world's poor (Runge and Senauer, 2007; Rajagopal et al., 2007; Wright, 2014; Poudel et al., 2012; Abbott, Hurt and Tyner, 2008, 2009, 2011; de Gorter, Drabik and Just, 2013; Zilberman et al., 2012). De Gorter et al. (2013) analyze the impact of OECD biofuels policies on grain and oilseed prices in developing countries. Hausman (2012) examines the sugarcane and soybean acreage response to biofuels in Brazil. Hausman, Auffhammer and Berck (2012) analyze the impact of biofuels on farm acreage and food prices. White et al. (2009) analyze the cultural factors associated with the decisions farmers face in targeting crops for fuel production instead of food. Zhou and Babcok (2017) use the competitive storage model to estimate the impact of ethanol and fueling investment on corn prices.

We also build on the literature examining relationships among ethanol prices, energy prices, and feedstock prices. Serra et al. (2011) analyze the relationships between ethanol, corn, oil, and gasoline prices in the U.S. Hasanov, Do and Shaiban (2016) analyze the impact of crude oil price volatility on the price changes of major edible oils (rapeseed, soybean, and sunflower), which are the main feedstocks for the biodiesel industry in the European Union. De Nicola, De Pace and Hernandez (2016) analyze the co-movement of major energy, agricultural, and food commodity price returns. Fernandez-Perez, Frijns and Tourani-Rad (2016) analyze contemporaneous interactions among fuel, biofuel, and agricultural commodities. Kang, McIver and Yoon (2017) examine dynamic spillover effects among crude oil, precious metal, and agricultural commodity futures markets.

Our analysis of the E10 ethanol-blend policy in some provinces in China builds upon the work of Lin et al. (2009), who analyze the implications of an E10 ethanol-blend policy for California. Our analysis of ethanol policies in China relates to the literature on energy policies in China, including papers on the effects of energy policies on energy consumption (Lu et al., 2017); and on GDP, industrial output, and new energy profits (Lu, Lin Lawell and Song, 2017).

3. Methods

3.1 Ethanol Supply

We estimate a supply function for ethanol using the annual province-level panel data by regressing ethanol production by province on ethanol price, ethanol price interacted with the E10 legislation dummy, corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, and electricity price.

In particular, we estimate the following regression for ethanol supply:

$$q_{it}^{e} = x_{it}'\beta + \gamma t + \varepsilon_{it}, \quad (1)$$

where q_{it}^{e} is ethanol production in province *i* in year *t*; and where the regressors x_{it} for province *i* in year *t* include ethanol price, ethanol price interacted with the E10 legislation dummy, corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, and electricity price. We estimate the model with and without a time trend γt.

We include corn price and wheat price in our regression of ethanol supply since corn and wheat are the major feedstocks for ethanol in China.[6] We include electricity price in our regression of ethanol supply since electricity is an energy source used in ethanol production in China.

Since equilibrium prices and quantities are jointly determined by the intersection of supply and demand curves, price is endogenous in regressions of supply, and instruments are therefore needed for price in regressions of supply (Goldberger, 1991; Lin, 2011). We use gasoline #90 price, gasoline price interacted with the E10 legislation dummy, and GDP interacted with the E10 legislation dummy as instruments for ethanol price and ethanol price interacted with the E10 legislation dummy. Gasoline prices are demand shifters that do not directly affect ethanol supply except through their effects on the ethanol price, and therefore serve as a good instrument for ethanol price.[7]

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[6] Data for the price of cassava, the other feedstock used in China, are not available.
[7] We also assume that the production of ethanol and its use do not affect the gasoline price.

3.2 Plant Entry

We estimate a plant entry function for ethanol plant using annual province-level panel data by regressing a dummy for whether a plant entered in province *i* at time *t* on ethanol price, ethanol price interacted with the annual E10 legislation dummy, corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, and electricity price.

In particular, we estimate the following regression for plant entry:

$$I_{it} = x_{it}'\beta + \gamma t + \alpha_i + \varepsilon_{it}, \tag{2}$$

where I_{it} is a dummy for whether a plant entered in province *i* at time *t*; where the regressors x_{it} for province *i* in year *t* include ethanol price, ethanol price interacted with the annual E10 legislation dummy, corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, and electricity price; where γt is a time trend; and where α_i is a province fixed effect.

We estimate four specifications: an IV regression without a time trend; an IV regression with a time trend γt; an IV fixed effects regression with a time trend γt and province fixed effects α_i; and IV probit regression with a time trend γt.

We use 90# gasoline price and GDP interacted with the E10 legislation dummy as instruments for ethanol price and ethanol price interacted with E10 legislation dummy. Gasoline prices are demand shifters that do not directly affect ethanol plant entry except through their effects on the ethanol price, and therefore serve as a good instrument for ethanol price.

3.3 Crop Production

We estimate crop production functions for corn, wheat, and cassava – the feedstocks used for producing ethanol in China – using annual province-level panel data.

For the corn production function, we regress corn production on province-level corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, average corn season precipitation, average corn season temperature, average corn season precipitation squared, average corn season temperature squared, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

In particular, we estimate the following corn production function:

$$q_{it}^{c} = x_{it}'\beta + \gamma t + \varepsilon_{it}, \tag{3}$$

where q_{it}^{c} is corn production in province *i* in year *t*; and where the regressors x_{it} for province *i* in year *t* include corn price, wheat price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, average corn season precipitation, average corn season temperature, average corn season precipitation squared, average corn season temperature squared, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

We estimate the corn production function (3) with and without a time trend γt. We use national corn price as an instrument for province-level corn price. National corn prices are assumed not to directly affect corn crop production except through their effects on the province-level corn price, and therefore serve as a good instrument for province-level corn price.

For the wheat production function, we regress wheat production on province-level wheat price, corn price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, average wheat season precipitation, average wheat season temperature, average wheat season precipitation squared, average wheat season temperature squared, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

In particular, we estimate the following wheat production function:

$$q_{it}^{w} = x_{it}'\beta + \gamma t + \varepsilon_{it}, \tag{4}$$

where q_{it}^{w} is wheat production in province *i* in year *t*; and where the regressors x_{it} for province *i* in year *t* include wheat price, corn price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, average wheat season precipitation, average wheat season temperature, average wheat season precipitation squared, average wheat season temperature squared, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

We estimate the wheat production function (4) with and without a time trend γt. We use national wheat price as an instrument for province-level wheat price. National wheat prices do not directly affect wheat crop production except through their effects on the province-level wheat price.

For the cassava production function, we regress cassava production on province-level corn price and wheat price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, province level temperature for each month, province level temperature for each month, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

In particular, we estimate the following cassava production function:

$$q_{it}^{v} = x_{it}'\beta + \gamma t + \varepsilon_{it}, \tag{5}$$

where q^{v}_{it} is cassava production in province *i* in year *t*; and where the regressors x_{it} for province *i* in year *t* include corn price and wheat price, the annual E10 legislation dummy, the ethanol subsidy, electricity price, province level temperature for each month, province level temperature for each month, chemical fertilizer price index, pesticide and appliance price index, lagged corn production, lagged wheat production and lagged cassava production.

We estimate the cassava production function (5) with and without a time trend γt. As we were unable to obtain data on cassava price, we do not include cassava price in the cassava production regression, and therefore do not instrument for cassava price.

3.4 Vector Autoregression

To examine the relationships among ethanol price, corn price, gasoline price, the E10 ethanol-blend policy, and the ethanol production subsidy, we estimate a vector autoregression model. For the first specification, we estimate the following vector autoregression of ethanol price (*ethanolp*), corn price (*cornp*), wheat price (*wheatp*), the number of provinces with an E10 policy (*E10*), and the ethanol subsidy (*subsidy*):

$$
\begin{aligned}
ethanolp_t &= \beta_{10} + \beta_{11} ethanolp_{t-1} + \beta_{12} cornp_{t-1} + \beta_{13} wheatp_{t-1} + \beta_{14} E10_{t-1} + \beta_{15} subsidy_{t-1} + \varepsilon_{1t} \\
cornp_t &= \beta_{20} + \beta_{21} ethanolp_{t-1} + \beta_{22} cornp_{t-1} + \beta_{23} wheatp_{t-1} + \beta_{24} E10_{t-1} + \beta_{25} subsidy_{t-1} + \varepsilon_{2t} \\
wheatp_t &= \beta_{30} + \beta_{31} ethanolp_{t-1} + \beta_{32} cornp_{t-1} + \beta_{33} wheatp_{t-1} + \beta_{34} E10_{t-1} + \beta_{35} subsidy_{t-1} + \varepsilon_{3t} \\
E10_t &= \beta_{40} + \beta_{41} ethanolp_{t-1} + \beta_{42} cornp_{t-1} + \beta_{43} wheatp_{t-1} + \beta_{44} E10_{t-1} + \beta_{45} subsidy_{t-1} + \varepsilon_{4t} \\
subsidy_t &= \beta_{50} + \beta_{51} ethanolp_{t-1} + \beta_{52} cornp_{t-1} + \beta_{53} wheatp_{t-1} + \beta_{54} E10_{t-1} + \beta_{55} subsidy_{t-1} + \varepsilon_{5t}
\end{aligned}
$$

For the second specification, we estimate the following vector autoregression of ethanol price (*ethanolp*), corn price (*cornp*), national 90# gasoline price (*gasop*), the number of provinces with an E10 policy (*E10*), and the ethanol subsidy (*subsidy*):

$$
\begin{aligned}
ethanolp_t &= \beta_{10} + \beta_{11} ethanolp_{t-1} + \beta_{12} cornp_{t-1} + \beta_{13} gasop_{t-1} + \beta_{14} E10_{t-1} + \beta_{15} subsidy_{t-1} + \varepsilon_{1t} \\
cornp_t &= \beta_{20} + \beta_{21} ethanolp_{t-1} + \beta_{22} cornp_{t-1} + \beta_{23} gasop_{t-1} + \beta_{24} E10_{t-1} + \beta_{25} subsidy_{t-1} + \varepsilon_{2t} \\
gasop_t &= \beta_{30} + \beta_{31} ethanolp_{t-1} + \beta_{32} cornp_{t-1} + \beta_{33} gasop_{t-1} + \beta_{34} E10_{t-1} + \beta_{35} subsidy_{t-1} + \varepsilon_{3t} \\
E10_t &= \beta_{40} + \beta_{41} ethanolp_{t-1} + \beta_{42} cornp_{t-1} + \beta_{43} gasop_{t-1} + \beta_{44} E10_{t-1} + \beta_{45} subsidy_{t-1} + \varepsilon_{4t} \\
subsidy_t &= \beta_{50} + \beta_{51} ethanolp_{t-1} + \beta_{52} cornp_{t-1} + \beta_{53} gasop_{t-1} + \beta_{54} E10_{t-1} + \beta_{55} subsidy_{t-1} + \varepsilon_{5t}
\end{aligned}
$$

For the third specification, we estimate the following vector autoregression of ethanol price (*ethanolp*), wheat price (*wheatp*), national 90# gasoline price (*gaso*), the number of provinces with an E10 policy (*E10*), and the ethanol subsidy (*subsidy*):

$$
\begin{aligned}
ethanolp_t &= \beta_{10} + \beta_{11} ethanolp_{t-1} + \beta_{12} wheatp_{t-1} + \beta_{13} gasop_{t-1} + \beta_{14} E10_{t-1} + \beta_{15} subsidy_{t-1} + \varepsilon_{1t} \\
wheatp_t &= \beta_{20} + \beta_{21} ethanolp_{t-1} + \beta_{22} wheatp_{t-1} + \beta_{23} gasop_{t-1} + \beta_{24} E10_{t-1} + \beta_{25} subsidy_{t-1} + \varepsilon_{2t} \\
gasop_t &= \beta_{30} + \beta_{31} ethanolp_{t-1} + \beta_{32} wheatp_{t-1} + \beta_{33} gasop_{t-1} + \beta_{34} E10_{t-1} + \beta_{35} subsidy_{t-1} + \varepsilon_{3t} \\
E10_t &= \beta_{40} + \beta_{41} ethanolp_{t-1} + \beta_{42} wheatp_{t-1} + \beta_{43} gasop_{t-1} + \beta_{44} E10_{t-1} + \beta_{45} subsidy_{t-1} + \varepsilon_{4t} \\
subsidy_t &= \beta_{50} + \beta_{51} ethanolp_{t-1} + \beta_{52} wheatp_{t-1} + \beta_{53} gasop_{t-1} + \beta_{54} E10_{t-1} + \beta_{55} subsidy_{t-1} + \varepsilon_{5t}
\end{aligned}
$$

After each specification of our vector autoregression model, we conduct pairwise Granger causality tests between each of the variables in the model.[8]

4. Data

We collect and construct an annual province-level panel data set over the time period 2002 to 2012. Our time period was chosen based on data availability.

Most of the data on ethanol production comes from the annual reports of fuel ethanol companies (Anhui Bio-Chemical Co., 2005; Anhui BBCA Bio-Chemical Co., Ltd. 2007a, 2009a; COFCO Bio-Chemical (ANHUI) Co., Ltd., 2013; CCXI 2014; Henan Tianguan Fuel Ethanol Co.,

[8] We unfortunately do not have enough annual observations of data to run the vector autoregression models with more than one lag or in first differences, and we unfortunately do not have enough annual observations of data to test for cointegration.

Ltd., 2012, 2014). For each year, we calculate ethanol production by dividing the total amount of fuel ethanol subsidy these companies received from the government that year by the unit subsidy that year. The remainder of the ethanol production data come directly from USDA-FAS's China's biofuel report in 2011 (Scott and Jiang, 2011) and CNSTRA Industrial Technology Analysis Center (Hu, 2011).

The national ethanol price data are collected from Price Yearbook of China 2003-2012, a series of book published each year containing previous year's price information. For the books from the years 2008 to 2012, the prices are published as the average monthly price for 36 big cities, while for the rest of the books from the years 2003 to 2007, the prices are published as the annual price for each of the 36 big cities. We used both type of prices to calculate the national average ethanol price through averaging all the available price data, and giving all the provinces the same price for the same year.

The E10 mandate information come from multiple government announcements (The People's Government of Jilin Province, 2003; The People's Government of Liaoning Province, 2004; The People's Government of Heilongjiang Province, 2004; The People's Government of Henan Province, 2004; The People's Government of Hubei Province, 2005; The People's Government of Shandong Province, 2005; Xinhua Net, 2005; The People's Government of Anhui Province, 2005; The People's Government of Hebei Province, 2006; The People's Government of Guangxi Province, 2007). We use this information to create an E10 dummy which is equal to 1 for a given province in a given year if that province has an E10 mandate in that year, and 0 otherwise. We also create a variable counting the total number of provinces that have an E10 mandate in each year.

For the ethanol subsidy, ideally we want to collect this data from government announcements; however, these announcements are not open to the public. Most of our data come from public announcements made by fuel ethanol production companies in the stock market (Anhui BBCA Bio-Chemical Co., Ltd., 2007b, 2009b, 2012, 2014). The rest of the data come from public news reports (Shang Hai Securities News, 2010).

Electricity price data are collected from Price Yearbook of China 2003-2012 as electricity prices for industrial use.

90# gasoline price data are collected from International Petroleum Economics, a monthly magazine containing monthly gasoline price information. The original data are monthly prices and we convert them into annual prices through averaging all the available months' prices for a certain year and province. We use the average price over all provinces in a given year to represent the national 90# gasoline price in that year.

Corn production, wheat production, and GDP data are collected from the Database of National Bureau of Statistics of China.

The data on cassava production are collected from multiple sources, mostly from the Province Statistical Yearbook of Guangdong Province, Hainan Province, and Guangxi Province. The cassava production is published in two ways as fresh cassava and dried cassava; to keep consistency we have converted the all cassava production into dried cassava (Mr. Tapioca, 2012). Because cassava is a tropical crop, it is only produced in a small number of provinces in China. Thus, cassava production is equal to 0 for those provinces that never had or are not suitable for cassava production.

Our data on ethanol plant entry come from fuel ethanol companies' self-description or CNSTRA Industrial Technology Analysis Center's report on fuel ethanol market. Jilin started the first ethanol plant in year 2003 (Jilin Fuel Alcohol Co., Ltd., 2015). Anhui constructed an ethanol plant in year 2005 (Anhui Bio-Chemical Co., Ltd., 2005). Heilongjiang, Henan and Guangxi constructed their ethanol plants in 2007 (Hu, 2011).

The national corn price and national wheat price data are collected from National Agriculture Products & Revenue Yearbook 2003-2012. Each year's data comes from previous year's yearbook.

Our province-level corn price data are mostly from National Agriculture Products Costs & Revenue Yearbook 2003-2012, a series of yearbooks that provides costs and revenue information for agricultural products. At the same time, we also use price information collected from the China Animal Industry Yearbook 2002-2012 to fill in the blanks left by the National Agriculture Products Costs & Revenue Yearbook 2003-2012. The second data reference used here gives corn prices in CNY/kg, and we convert the unit into CNY/50 kg in order to keep consistency between these two data sources.

Our province-level wheat price data come mostly from National Agriculture Products Costs & Revenue Yearbook 2003-2012, while we use the China Yearbook of Agricultural Price Survey 2002-2012 to fill in the blanks left by the National Agriculture Products Costs & Revenue Yearbook 2003-2012. Also, the second data source we use here gives wheat prices in CNY/kg, and we convert the units into CNY/50 kg to keep consistency between the two data sources. For some years, wheat price is only reported as year-to-year percentage change, in China Yearbook of Agricultural Price Survey 2002-2012; we therefore use existing wheat prices to calculate the actual wheat prices for these years.

We also use data on the chemical fertilizer price index and pesticides and appliance price index to help explain crop production. Both of the data are collected from Chinese Statistic Yearbook 1996-2013. While the original data use each previous year as the base year, we convert the data to use 1995 as the base year for all the data.

China Maize (2015) divides China into 5 major corn growing districts that each have their own distinct corn growing season. We created the corn growing season dummy according to this information. Most provinces fall into a certain corn-growing district, while some fall into two or three districts. We consider the corn-growing season for those provinces that fall into only one district to be the corn growing season for that district. For those provinces that fall into multiple districts, we consider their corn growing season to be the combined corn growing season months for all the districts they fall into. We set the corn growing season dummy equal to 1 for those months in a province's corn growing season, and 0 otherwise.

We use the description of wheat future products retrieved from Haitong Securities Co. Ltd. (Haitong Securities, 2012), a futures trading company that involves in wheat futures product trading, to determine the growing season for wheat and thus to create the wheat growing season dummy. This article clearly identifies the growing months for each types of wheat as well as which types of wheat is grown in a certain province. We consider the wheat-growing season for a certain province as the combined months of all the growing months over all types of wheat grown in this province. We set the wheat growing season dummy equal to 1 for those months in a province's wheat growing season, and 0 otherwise.

Information on the corn and wheat growing season information is presented in Table 2. Cassava is grown year-round.

To explain the influence of weather on crop production, we use monthly province level data on average precipitation and average temperature from the Chinese Statistic Yearbook 1996-2013. We calculate the average corn season temperature for each province in each year by averaging the monthly temperature for that province in that year over all the months in the corn growing season. We calculate the average corn season precipitation for each province in each year by averaging the monthly precipitation for that province in that year over all the months in the corn growing season. We calculate the average wheat season temperature for each province in each year by averaging the monthly temperature for that province in that year over all the months in the wheat growing season. Similarly, we calculate the average wheat season precipitation for each province in each year by averaging the monthly precipitation for that province in that year over all the months in the wheat growing season.

Summary statistics for all our variables are presented in Table 3.

5. Results

5.1 Ethanol Supply

The first-stage regressions for our ethanol supply models are presented in Table 4 and the results of underidentification tests, weak-instrument-robust inference tests, and tests of overidentifying restrictions are presented along with the IV results for ethanol supply in Table 5. We pass the underidentification tests, weak-instrument-robust inference tests, and tests of overidentifying restrictions; and the Angrist-Pischke first-stage F-statistics are all greater than 10.

The results of our ethanol supply regressions are presented in Table 5. The results are robust across both specifications. For both specifications, the coefficient on ethanol price is significant and positive. For both specifications, the coefficient on ethanol price interacted with the E10 dummy is not significant, so the E10 policy did not have a significant effect on the supply elasticity. For both specifications, E10 has a significant positive effect on ethanol supply. Having an E10 policy increases ethanol production by 645,940 to 647,040 tons, relative to the case when there is no E10 policy. For both specifications, subsidy has no significant effect on ethanol supply.

5.2 Plant Entry

The first-stage regression for our plant entry models are presented in Table 6 and the results of underidentification tests, weak-instrument-robust inference test, and tests of overidentifying restrictions presented along with the IV results for plant entry in Table 7. We pass the underidentification tests and the Angrist-Pischke first-stage F-statistics are all greater than 10. Specifications (1) and (2) pass the weak-instrument-robust inference tests.

The results of our plant entry models are presented in Table 7. The results are robust across all specifications. For all specifications, the coefficient on ethanol price has a significant and positive effect on plant entry. In all specifications, the coefficient on ethanol price interacted with the E10 dummy is negative and greater in magnitude than the coefficient on ethanol price and, for most specifications, is significant. Thus, when the E10 policy is in place ethanol price has a net negative effect on plant entry. E10 has a significant and positive coefficient in all specification except the IV fixed-effects with a time trend and province fixed effects. Having an E10 policy increases the plant entry probability by 4.891 to 12.969. For all specifications, ethanol subsidy has no significant effect on plant entry.

5.3 Crop Production

The first-stage regression for our corn production models are presented in Table 8 and the results of underidentification tests, weak-instrument-robust inference tests, and tests of overidentifying restriction are presented along with the IV corn production results in Table 9. We pass the underidentification tests and the tests of overidentifying restrictions; and the Angrist-Pischke first-stage F-statistics are all greater than 10. Neither specification passes the weak-instrument robust inference tests, so the coefficient on corn price is not significant.

The results of our corn production regressions are presented in Table 9. The results are robust across both specifications. For both specifications, the coefficient on corn price has no significant effect on corn production. For both specifications, the E10 dummy has significant positive effect on corn production. Having an E10 policy increases corn production by 449,930 to 521,820 tons. For both specifications, ethanol subsidy has a negative effect that is significant at a 10% level. If the ethanol subsidy increases by 100 CNY/ton, then corn production decreases by 35,000 to 350,000 tons. For both specifications, lagged corn production has a significant positive effect.

The first-stage regression for our wheat production models are presented in Table 10 and the results of underidentification tests, weak-instrument-robust inference tests, and tests of overidentifying restriction are presented with the IV wheat production results in Table 11. We pass the underidentification tests and the tests of overidentifying restrictions; and the Angrist-Pischke first-stage F-statistics are all greater than 10. Neither specification passes the weak-instrument robust inference tests, so the coefficient on wheat price is not significant.

The results of our wheat production regressions are presented in Table 11. The results are robust across both specifications. For both specifications, the coefficient on wheat price has no significant effect on wheat production. For both specifications, the E10 dummy has no significant effect on wheat production. For both specifications, ethanol subsidy has a significant negative effect. If the ethanol subsidy increases by 100 CNY/ton, then wheat production decreases by 35,000 to 36,000 tons. For both specifications, lagged wheat production has a significant positive effect on wheat production. And for the specification without a time trend, average wheat season temperature squared has a negative effect that is significant at a 10% level.

The results for our cassava production models are presented in Table 12. The results are robust across both specifications. For both specifications, the coefficient on E10 policy dummy has no significant effect on cassava production. For both specifications, ethanol subsidy has a significant negative effect on cassava production. If the ethanol subsidy increases by 100 CNY/ton, then cassava production decreases by 3,400 to 3,500 tons. For both specifications, average temperature in May has a significant negative effect on cassava production while average temperature in August has a significant positive effect on cassava production. For both specifications, lagged wheat production has a significant negative effect on cassava production while lagged cassava production has a significant positive effect on cassava production. For the specification with a time trend, corn price has a significant negative effect on cassava production while time variable has a significant positive effect on cassava production.

5.4 Vector Autoregression

The results of our vector autoregression models are presented in Table 13. We conduct pairwise Granger causality tests for all three specifications, and the Granger causality results are presented in Table 14 to 16.

Several results are robust across all vector autoregression models. First, the number of provinces with an E10 policy significantly Granger-causes corn price, wheat price, and gasoline price at a 5% level. Second, the number of provinces with an E10 policy does not Granger-cause ethanol price except when corn price is not included in the model. Third, the ethanol subsidy does not Granger-cause ethanol price and except when wheat price is not included in the model. Fourth, the ethanol subsidy significantly Granger-causes wheat price and gasoline price at a 5% level. Fifth, the ethanol price significantly Granger-causes corn price, wheat price, and gasoline price at a 5% level. Sixth, corn and wheat prices significantly Granger-cause each other at a 5% level.

Thus, ethanol policies such as the E10 policy and the ethanol subsidy can Granger-cause feedstock price and gasoline price, but generally does not Granger-cause ethanol price. The ethanol price Granger-causes feedstock prices and gasoline price. Feedstock prices Granger-cause each other, consistent with a law of one price for crops that arises because crops compete with each other for land (de Gorter, Drabik and Just, 2015).

6. Conclusion

In this paper, we examine the effects of China's biofuel policies on agricultural markets and the ethanol market in China. In particular, we use econometric analyses to examine the effects of the E10 policy and the ethanol production subsidy in China on ethanol supply, ethanol plant entry, ethanol prices, corn production, wheat production, cassava production, crop prices, and gasoline prices. We use instrumental variables to address the endogeneity of prices in our econometric models of ethanol supply, ethanol plant investment and feedstock crop production. We use vector autoregression models and Granger causality tests to examine the relationships among ethanol price, corn price, gasoline price, the E10 ethanol-blend policy, and the ethanol production subsidy.

Our results indicate that the E10 ethanol-blend policy has a positive effect on ethanol supply, ethanol plant entry, and corn production, but no significant effect on the supply elasticity, wheat production, or cassava production.

We find that when the E10 ethanol-blend policy is in place, ethanol price has a net negative effect on ethanol plant entry. In other words, for a given mandate, when the ethanol price increases, fewer ethanol plants are opened. One possible mechanism is that if the ethanol price increases due to an increase in energy prices, then the increase in energy prices would also increase the price of gasoline, which would decrease the demand for gasoline and therefore the mandated amount of ethanol, thereby decreasing the need for ethanol supply. Similarly, if the ethanol price increases due to a shock to fuel production costs, then the increase in fuel production costs would also increase the price of gasoline, which would decrease the demand for gasoline and therefore the mandated amount of ethanol, thereby decreasing the need for ethanol supply.

The production subsidy has a negative effect on wheat production and cassava production, but no significant effect on ethanol supply or ethanol plant entry.

We find that ethanol policies such as the E10 policy and the ethanol subsidy can Granger-cause feedstock price and gasoline price, but generally does not Granger-cause ethanol price. One possible explanation is that the Chinese government fixes ethanol price at 91.1 percent of the #93 gasoline ex-factory variable price. The ethanol price Granger-causes feedstock prices and gasoline price.

We also find that feedstock prices Granger-cause each other, consistent with a law of one price for crops that arises because crops compete with each other for land (de Gorter, Drabik and Just, 2015).

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Table 1a. Provinces with an E10 Ethanol-Blend Policy

Province	Implementation Date	Source
Jilin	August 10, 2003	The People's Government of Jilin (2003)
Heilongjiang	October 22, 2004	The People's Government of Heilongjiang Province (2004)
Liaoning	November 1, 2004	The People's Government of Liaoning Province (2004)
Henan	December 1, 2004	The People's Government of Henan Province (2004)
Anhui	April 1, 2005	The People's Government of Anhui Province (2005)
Hubei	December 23, 2005	The People's Government of Hubei Province (2005)
Jiangsu	January 1, 2006	Xinhua Net (2005)
Shandong	January 8, 2006	The People's Government of Shandong Province (2005)
Hebei	February 1, 2006	The People's Government of Hebei Province (2006)

Table 1b. Ethanol Subsidy

Year	Ethanol Subsidy (CNY/ton)
2004	1880
2005	1883
2006	1373
2007	2251
2008	2185
2009	2055
2010	1659
2011	1276
2012	500
2013	300
2014	200

Sources: Gong (2007); Anhui BBCA Bio-Chemical Co., Ltd. (2007b); Anhui BBCA Bio-Chemical Co., Ltd. (2009b); Shang Hai Securities News (2010); Anhui BBCA Bio-Chemical Co., Ltd. (2012); Anhui BBCA Bio-Chemical Co., Ltd. (2014).

Table 2. Crop Growing Seasons

Province	Corn	Wheat
Beijing	March-October	September-next June
Tianjin	March-October	September-next June
Hebei	March-October	March – August
Shanxi	March-October	September-next June
Neimenggu	May-October	March - August
Liaoning	May-October	September-next June
Jilin	May-October	April – July
Heilongjiang	May-October	April – July
Shanghai	All year round	October – next May
Jiangsu	March-October	October – next May
Zhejiang	All year round	October – next May
Anhui	All year round	October – next May
Fujian	All year round	November – next April
Jiangxi	All year round	October – next May
Shandong	March-October	October – next June
Henan	March-October	October – next May
Hubei	All year round	October – next May
Hunan	All year round	October – next May
Guangdong	All year round	November – next April
Guangxi	All year round	November – next April
Hainan	All year round	November – next April
Chongqing	May-October	October – next May
Sichuan	May-October	All-Year-Round
Guizhou	May-October	October – next May
Yunnan	May-October	All-Year-Round
Xizang	April-September	All-Year-Round
Shannxi	March-October	October – next June
Gansu	March-October	All-Year-Round
Qinghai	April-September	All-Year-Round
Ningxia	May-October	September – next June
Xinjiang	May-October	All-Year-Round

Sources: China Maize, 2015; Haitong Securities Co. Ltd., 2012.

Table 3. Summary Statistics Table

Variable Name	# Obs.	Mean	Std. Dev.	Min	Max
ethanol production (10,000 tons)	426	3.07	10.94	0	65.33
national ethanol price (CNY/ton)	372	4597.45	1557.09	340.4	7335.83
national ethanol price (CNY/ton) * E10 dummy	372	935.04	2071.22	0	7335.83
national corn price (CNY/50kg)	434	72.53	23.38	42.81	111.13
national wheat price (CNY/50kg)	403	76.17	19.28	51.25	108.31
E10 dummy	775	0.12	0.32	0	1
ethanol subsidy (CNY/ton)	341	1414.73	725.57	200	2251
electricity price (CNY/kWh)	310	0.63	0.1	0.46	0.76
90# gasoline price (CNY/ton)	479	5604.09	2615.78	1465.45	9761.25
90# gasoline price (CNY/ton) * E10 dummy	479	1246.57	2874.57	0	9585
GDP (100 million CNY)	619	6516.218	8375.262	37.42	57067.92
GDP (100 million CNY) * E10	619	2030.94	6869.64	0	54058.22
probability of ethanol plant entry at time t	775	0.07	0.25	0	1
corn production (10,000 tons)	697	435.3	530.53	0.89	2887.94
corn price (CNY/50kg)	340	80.88	22.1	44.08	135.42
wheat price (CNY/50kg)	288	87.77	26.61	40.3	217.5
average corn season temperature (°C)	558	13.26	4.76	6.11	25.36
average corn season temperature squared	558	198.36	137.78	37.31	643.05
average corn season precipitation (mm)	558	68.21	42.77	5.84	223.24
average corn season precipitation squared	558	6478.43	7944.59	34.08	49836.84
chemical fertilizer price index (base year is 1995)	468	113.11	27.52	72.34	212.63
pesticides & appliance price index (base year is 1995)	468	106.47	14.73	78.54	169.52
wheat Production (10,000 tons)	683	354.28	578.15	0	3177.35
average wheat season temperature (°C)	558	9.25	2.37	3.96	18.33
average wheat season temperature squared	558	91.06	53.17	15.67	335.81
average wheat season precipitation (mm)	558	41.7	19.4	5.62	130.33
average wheat season precipitation squared	558	2114.6	2190.08	31.56	16986.78
cassava production (10,000 tons)	671	10.95	57.54	0	1132.33
average precipitation in Jan (mm)	512	20.89	28.75	0	193.9

average precipitation in Feb (mm)	516	34.28	40.68	0	292.1
average precipitation in Mar (mm)	552	53.33	92.07	0	1212.9
average precipitation in Apr (mm)	558	75.49	67.98	0.4	566.5
average precipitation in May (mm)	558	137.1	89.83	4	542.7
average precipitation in Jun (mm)	558	152.07	99.83	1.9	758.4
average precipitation in Jul (mm)	557	140.39	124.49	0.3	834.6
average precipitation in Aug (mm)	558	97.02	93.42	0.2	663.4
average precipitation in Sept (mm)	554	66.68	73.16	0	418.7
average precipitation in Oct (mm)	535	47.19	55.89	0	300.4
average precipitation in Nov (mm)	526	28.67	37.06	0	225.8
average precipitation in Dec (mm)	515	28.56	37.17	0	279.7
average temperature in Jan (mm)	556	2.4	8.13	-19.4	20.8
average temperature in Feb (mm)	558	8.47	7.02	-9.1	25.3
average temperature in Mar (mm)	558	15.44	5.35	3.1	27.1
average temperature in Apr (mm)	558	21.06	4.17	10.5	29.5
average temperature in May (mm)	558	24.96	3.7	14.1	32.4
average temperature in Jun (mm)	558	25.99	3.57	14.4	31.8
average temperature in Jul (mm)	558	23.99	3.21	12.9	29.4
average temperature in Aug (mm)	558	20.33	3.53	11	28.5
average temperature in Sept (mm)	558	15.27	4.34	4	26.7
average temperature in Oct (mm)	558	8.73	5.71	-7.2	23.2
average temperature in Nov (mm)	558	3.66	7.4	-16.7	22.5
average temperature in Dec (mm)	556	0.28	8.33	-22.8	19.1
number of provinces with E10 policy	775	3.68	4.21	0	9
national 90# gasoline price (CNY/ton)	558	5493.38	2532.84	2129.27	9590

Table 4. First-Stage Regressions for Ethanol Supply

	Dependent variable is:			
	(1)		(2)	
	ethanol price (CNY/ton)	ethanol price*E10 dummy	ethanol price (CNY/ton)	ethanol price *E10 dummy
instruments				
90# gasoline price (CNY/ton)	-0.265***	-0.023*	-0.311***	-0.037***
	(0.008)	(0.011)	(0.008)	(0.011)
90# gasoline price (CNY/ton) * E10 dummy	-0.001	-0.212***	0.002	-0.211***
	(0.012)	(0.047)	(0.011)	(0.047)
GDP (100 million CNY) * E10 dummy	0.003	0.032***	0.003	0.032***
	(0.003)	(0.006)	(0.003)	(0.006)
controls				
corn price (CNY/50 kg)	35.333***	9.357	21.470***	5.140
	(5.264)	(5.982)	(4.596)	(5.953)
wheat price (CNY/50 kg)	-20.671***	1.012	-43.022***	-5.785
	(4.774)	(6.124)	(3.936)	(6.076)
E10 dummy	-87.323	6182.772***	-91.828	6181.402***
	(72.94)	(1180.942)	(61.474)	(322.028)
ethanol subsidy (CNY/ton)	-0.377***	-0.128*	-0.433***	-0.145*
	(0.050)	(0.064)	(0.039)	(0.064)
electricity price (CNY/kWh)	7575.935***	-331.2594	-9129.292***	-5411.321***
	(762.277)	(1180.942)	(798.725)	(1177.293)
year			715.597***	217.613***
			(15.261)	(0.209)
Angrist-Pischke F-statistic	439.08	21.55	539.88	21.69
p-value (Pr > F)	[0.0000]***	[0.0000]***	[0.0000]***	[0.0000]***
R-squared	0.9979	0.9853	0.9986	0.9855
# of observations	204	204	204	204

Notes: Robust standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 5. IV Results for Ethanol Supply

	(1)	(2)
Dependent variable is ethanol production (10,000 tons)		
ethanol price (CNY/ton)	0.003*	0.003*
	(0.001)	(0.002)
ethanol price (CNY/ton) * E10	-0.010	-0.010
	(0.006)	(0.006)
corn price (CNY/50 kg)	-0.124	-0.122
	(0.205)	(0.199)
wheat price (CNY/50 kg)	0.367*	0.364
	(0.182)	(0.191)
E10 dummy	64.594*	64.704*
	(31.369)	(31.559)
ethanol subsidy (CNY/ ton)	-0.003	-0.003
	(0.002)	(0.002)
electricity price (CNY/kWh)	-29.384	-30.820
	(31.804)	(75.518)
year		-0.006
		(2.491)
p-value from Anderson under-identification test	[0.0004]***	[0.0005]***
Weak-instrument-robust-inference tests		
p-value from Anderson-Rubin F test	[0.0009]***	[0.0005]***
p-value from Anderson-Rubin Chi-sq test	[0.0004]***	[0.0002]***
p-value from Stock-Wright S statistic test	[0.0392]*	[0.0308]*
p-value from Sargan-Hansen test of overidentifying restrictions	[0.0630]	[0.0509]
p-value (Pr > F)	[0.0052]**	[0.0084]**
R-squared	0.1301	0.1292
# of observations	204	204

Notes: Robust standard errors are in parentheses. We use the following variables as instruments for ethanol price and ethanol price * E10 dummy: 90# gasoline price, 90# gasoline price * E10 dummy, and GDP * E10 dummy. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 6. First-Stage Regressions for Ethanol Plant Entry

	Dependent variable is:							
	(1)		(2)		(3)		(4)	
	ethanol price (CNY/ton)	ethanol price* E10 dummy	ethanol price (CNY/ton)	ethanol price * E10 dummy	ethanol price (CNY/ton)	ethanol price* E10 dummy	ethanol price (CNY/ton)	ethanol price* E10 dummy
Instruments								
90# gasoline price (CNY/ton)	-0.265***	-0.086***	-0.310***	-0.100***	-0.312***	-0.099***	-0.310***	-0.100***
	(0.0007)	(0.025)	(0.007)	(0.027)	(0.008)	(0.026)	(0.008)	(0.024)
GDP (100 million CNY) *E10 dummy	0.003	0.029***	0.003	0.029***	0.0004	0.073***	0.003	0.029***
	(0.003)	(0.008)	(0.002)	(0.008)	(0.003)	(0.013)	(0.002)	(0.007)
Controls								
corn price (CNY/50 kg)	35.654***	9.807	21.865***	5.703	21.234***	3.746	21.865***	5.703
	(5.274)	(5.485)	(4.620)	(5.675)	(4.855)	(4.560)	(4.595)	(5.497)
wheat price (CNY/50 kg)	-20.476***	-2.185	-42.196***	-8.649	-42.082***	-16.189*	-42.196***	-8.650
	(4.784)	(5.704)	(3.843)	(6.657)	(4.652)	(6.752)	(4.187)	(6.400)
E10 dummy	-86.581	4914.924***	-85.260	4915.317***	-83.542	3646.204***	-85.260	4915.305***
	(57.841)	(149.723)	(46.362)	(148.415)	(90.754)	(388.219)	(45.953)	(1906.597)
ethanol subsidy (CNY/ton)	-0.369***	-0.116*	-0.428***	-0.133*	-0.443***	-0.123**	-0.428***	-0.133*
	(0.049)	(0.056)	(0.038)	(0.056)	(0.038)	(0.044)	(0.0381)	(0.055)
electricity price (CNY/kWh)	7450.783***	655.088	-8834.365***	-4191.613	-9066.699***	-2951.996	-8834.302***	-4191.744*
	(749.559)	(948.350)	(644.462)	(2138.712)	(1214.298)	(2119.94)	(1223.031)	(1906.597
Year			699.937***	208.312*	715.347***	209.086*	699.934***	208.317*
			(0.187)	(94.608)	(42.180)	(100.406)	(39.907)	(83.301)
Angrist-Pischke F-statistic	506.50	641.88	630.46	12.95	1173.73	29.53	N/A	N/A
p-value (Pr > F)	[0.0000]***	[0.0000]***	[0.0000]***	[0.0000]***	[0.0000]***	[0.0000]***	N/A	N/A
R-squared	0.9979	0.9807	0.9986	0.9810	0.9575	0.8914	N/A	N/A
# of observations	209	209	209	209	208	208	209	209

Notes: Robust standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 7. IV Results for Ethanol Plant Entry

Dependent variable is probability of ethanol plant entry at time t				
Probability model:	linear	linear	linear	probit
	(1)	(2)	(3)	(4)
ethanol price (CNY/ton)	0.0003*	0.0003*	0.00002	0.0008***
	(0.0001)	(0.0001)	(0.00003)	(0.0002)
ethanol price (CNY/ton) * E10 dummy	-0.0008**	-0.0008**	-0.00005	-0.002***
	(0.0003)	(0.0003)	(0.00008)	(0.0003)
corn price (CNY/50 kg)	-0.0038	-0.0052	-0.002	-0.023
	(0.0075)	(0.0075)	(0.002)	(0.026)
wheat price (CNY/50 kg)	0.0112	0.0099	-0.003	0.037
	(0.0077)	(0.0080)	(0.003)	(0.0274)
E10 dummy	4.8914***	4.8992***	0.325	12.969***
	(1.4616)	(1.4587)	(0.483)	(1.241)
ethanol subsidy (CNY/ton)	-0.0001	-0.0001	-0.000008	-0.0003
	(0.0001)	(0.0001)	(0.00002)	(0.0003)
electricity price (CNY/kWh)	-1.6996	-2.8986	0.639	-6.875
	(1.3905)	(1.7401)	(1.048)	(8.994)
year		0.0479	0.056	0.167
		(0.0538)	(0.048)	(0.358)
p-value from Anderson under-identification test	[0.0021]**	[0.0021]**	[0.0000]***	N/A
Weak-instrument-robust-inference tests				
p-value from Anderson-Rubin F test	[0.0000]***	[0.0000]***	[0.6806]	N/A
p-value from Anderson-Rubin Chi-sq test	[0.0000]***	[0.0000]***	[0.6678]	N/A
p-value from Stock-Wright S statistic test	[0.0003]***	[0.0003]***	[0.6824]	N/A
p-value (Pr > F or Pr > chi-squared)	[0.0014]**	[0.0022]**	[0.4935]	[0.0000]***
R-squared	-0.5987	-0.6024	0.0528	N/A
# of observations	209	209	208	209

Notes: Robust standard errors are in parentheses. We use the following variables as instruments for the ethanol production and ethanol production * E10: 90# gasoline price and province GDP * E10. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 8. First-Stage Regressions for Corn Production

	Dependent variable is corn price (CNY/50 kg)	
	(1)	(2)
instrument		
national corn price (CNY/50 kg)	0.963***	0.899***
	(0.085)	(0.085)
controls		
wheat price (CNY/50 kg)	-0.00002	-0.003
	(0.033)	(0.033)
E10 dummy	-6.383***	-6.628***
	(1.194)	(1.195)
ethanol subsidy (CNY/ton)	-0.0007	-0.0007
	(0.001)	(0.001)
electricity price (CNY/kWh)	23.435	-6.411
	(21.692)	(21.655)
average corn season temperature (°C)	-4.468***	-4.620***
	(0.987)	(0.995)
average corn season temperature squared	0.158***	0.164***
	(0.035)	(0.036)
average corn season precipitation (mm)	0.225***	0.222***
	(0.047)	(0.047)
average corn season precipitation squared	-0.0007*	-0.0007**
	(0.0003)	(0.0003)
chemical fertilizer price index (base year is 1995)	0.055	0.038
	(0.042)	(0.042)
pesticides & appliance price index (base year is 1995)	-0.227***	-0.226***
	(0.041)	(0.041)
lagged corn production (10,000 tons)	-0.002	-0.002
	(0.001)	(0.001)
lagged wheat production (10,000 tons)	0.003**	0.002**
	(0.0008)	(0.0009)
lagged cassava production (10,000 tons)	-0.038*	-0.041*

	(0.017)	(0.017)
year		1.489***
		(0.005)
Angrist-Pischke F-statistic	127.00	69.41
p-value (Pr > F)	[0.0000]***	[0.0000]***
R-squared	0.9965	0.9965
# of observations	170	170

Notes: Robust standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 9. IV Results for Corn Production

	Dependent variable is corn production (10,000 tons)	
	(1)	(2)
corn price (CNY/50 kg)	0.500	1.214
	(1.200)	(1.549)
wheat price (CNY/50 kg)	0.063	0.097
	(0.398)	(0.411)
E10 dummy	44.993*	52.182*
	(19.738)	(25.577)
ethanol subsidy (CNY/ton)	-0.35	-0.035
	(0.021)	(0.020)
electricity price (CNY/kWh)	-440.094	-135.798
	(289.386	(537.329)
average corn season temperature (°C)	-15.441	-10.617
	(12.975)	(14.844)
average corn season temperature squared	0.461	0.280
	(0.448)	(0.521)
average corn season precipitation (mm)	0.239	0.111
	(0.610)	(0.661)
average corn season precipitation squared	-0.0006	-0.0001
	(0.002)	(0.003)
chemical fertilizer price index (base year is 1995)	0.413	0.558
	(0.454)	(0.526)
pesticides & appliance price index (base year is 1995)	0.353	0.500
	(0.422)	(0.508)
lagged corn production (10,000 tons)	1.071***	1.073***
	(0.021)	(0.021)
lagged wheat production (10,000 tons)	-0.017	-0.020
	(0.019)	(0.019)
lagged cassava production (10,000 tons)	-0.025	0.026
	(0.164)	(0.0179))
year		-15.997
		(24.513)

p-value from Anderson Under-identification test	[0.0000]***	[0.0000]***
Weak-instrument-robust-inference tests		
p-value from Anderson-Rubin F test	[0.6902]	[0.3580]
p-value from Anderson-Rubin Chi-sq test	[0.6758]	[0.3327]
p-value from Stock-Wright S statistic test	[0.6766]	[0.4278]
p-value (Pr > F)	[0.00000]***	[0.0000]***
R-squared	0.9938	0.9937
# of observations	170	170

Notes: Robust standard errors are in parentheses. We use the national corn price as an instrument for corn price. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 10. First-Stage Regressions for Wheat Production

	Dependent variable is wheat price (CNY/50 kg)	
	(1)	(2)
instrument		
national wheat price (CNY/50 kg)	0.897***	0.752***
	(0.118)	(0.225)
controls		
corn price (CNY/50 kg)	0.107	0.065
	(0.0149)	(0.155)
E10 dummy	-10.121***	-10.684***
	(2.581)	(2.748)
ethanol subsidy (CNY/ton)	-0.003	-0.003
	(0.003)	(0.003)
electricity price (CNY/kWh)	7.876	-98.034
	(44.592)	(2.107)
average wheat season temperature (°C)	1.888	2.086
	(2.081)	(2.107)
average wheat season temperature squared	-0.165	-0.171
	(0.092)	(0.093)
average wheat season precipitation (mm)	0.154	0.162
	(0.245)	(0.244)
average wheat season precipitation squared	-0.0006	-0.0007
	(0.002)	(0.002)
chemical fertilizer price index (base year is 1995)	0.211**	0.171*
	(0.077)	(0.077)
pesticides & appliance price index (base year is 1995)	-0.328***	-0.325***
	(0.085)	(0.084)
lagged corn production (10,000 tons)	0.008***	0.008***
	(0.002)	(0.002)
lagged wheat production (10,000 tons)	-0.004**	-0.004*
	(0.002)	(0.002)

lagged cassava production (10,000 tons)	0.365***	0.362***
	(0.042)	(0.042)
year		4.539
		(4.215)
Angrist-Pischke F-statistic	25.48	11.52
p-value (Pr > F)	[0.0000]***	[0.0000]***
R-squared	0.9861	0.9862
# of observations	170	170

Notes: Robust standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 11. IV Results for Wheat Production

Dependent variable is wheat production (10,000 tons)		
	(1)	(2)
wheat price (CNY/50 kg)	-0.925	-0.732
	(1.063)	(1.059)
corn price (CNY/50 kg)	-0.290	-0.260
	(0.468)	(0.472)
E10 dummy	2.238	4.852
	(16.830)	(17.523)
ethanol subsidy (CNY/ton)	-0.036*	-0.035*
	(0.017)	(0.017)
electricity price (CNY/kWh)	53.255	177.069
	(149.866)	(195.794)
average wheat season temperature (°C)	9.903	9.305
	(6.331)	(6.259)
average wheat season temperature squared	-0.535	-0.497
	(0.317)	(0.316)
average wheat season precipitation (mm)	0.303	0.263
	(0.559)	(0.549)
average wheat season precipitation squared	-0.003	0.263
	(0.005)	(0.549)
chemical fertilizer price index (base year is 1995)	0.109	0.115
	(0.308)	(0.303)
pesticides & appliance price index (base year is 1995)	-0.185	-0.125
	(0.580)	(0.580)
lagged corn production (10,000 tons)	-0.003	-0.005
	(0.015)	(0.015)
lagged wheat production (10,000 tons)	1.030***	1.031***
	(0.010)	(0.010)
lagged cassava production (10,000 tons)	0.307	0.240
	(0.385)	(0.383)
year		-5.372
		(6.124)

p-value from Anderson under-identification test	[0.0000]***	[0.0014]**
Weak-instrument-robust-inference tests		
p-value from Anderson-Rubin F test	[0.3921]	[0.5519]
p-value from Anderson-Rubin Chi-sq test	[0.3688]	[0.5310]
p-value from Stock-Wright S statistic test	[0.3720]	[0.5381]
p-value (Pr > F)	[0.0000]***	[0.0000]***
R-squared	0.9974	0.9974
# of observations	170	170

Notes: Robust standard errors are in parentheses. We use the national wheat price as an instrument for wheat price. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 12. OLS Results for Cassava Production

Dependent variable is cassava production (10,000 tons)		
	(1)	(2)
corn price (CNY/50 kg)	-0.1010	-0.1631*
	(0.0533)	(0.0660
wheat price (CNY/50 kg)	-0.0001	-0.0011
	(0.0370)	(0.0353)
E10 dummy	1.0471	0.2485
	(0.8018)	(0.7645)
ethanol subsidy (CNY/ton)	-0.0034*	-0.0035 **
	(0.0013)	(0.0012)
electricity price (CNY/kWh)	7.2434	-120.7707
	(12.3651)	(67.3660)
average precipitation in Jan (mm)	0.0042	-0.0047
	(0.0217)	(0.0205)
average precipitation in Feb (mm)	0.0046	0.0045
	(0.0111)	(0.0108)
average precipitation in Mar (mm)	-0.0094	-0.0063
	(0.0091)	(0.0073)
average precipitation in Apr (mm)	-0.0039	-0.0087
	(0.0063)	(0.0063)
average precipitation in May (mm)	-0.0073	-0.0048
	(0.0052)	(0.0045)
average precipitation in Jun (mm)	0.0004	0.0009
	(0.0046)	(0.0042)
average precipitation in Jul (mm)	-0.0073	-0.0077
	(0.0058)	(0.0052)
average precipitation in Aug (mm)	-0.0115	-0.0086
	(0.0063)	(0.0061)
average precipitation in Sept (mm)	-0.0024	-0.0021
	(0.0082)	(0.0076)
average precipitation in Oct (mm)	0.0111	0.0068
	(0.0114)	(0.0104)
average precipitation in Nov (mm)	0.0028	0.0059
	(0.0144)	(0.0134)
average precipitation in Dec (mm)	0.126	0.0141
	(0.0132)	(0.0125)
average temperature in Jan (mm)	-0.5215	-0.3333
	(0.3268)	(0.2667)
average temperature in Feb (mm)	0.4738	0.1880
	(0.3000)	(0.2338)
average temperature in Mar (mm)	0.0859	0.1128
	(0.2393)	(0.2546)
average temperature in Apr (mm)	0.3556	0.0455
	(0.3615)	(0.3146)

average temperature in May (mm)	-1.1443**	0.7182*
	(0.3825)	(0.3581)
average temperature in Jun (mm)	0.3838	0.4149
	(0.4950)	(0.4686)
average temperature in Jul (mm)	-0.4533	-0.4671
	(0.3486)	(0.3282)
average temperature in Aug (mm)	1.1041*	1.1203*
	(0.5209)	(0.4888)
average temperature in Sept (mm)	-0.03755	-0.7120
	(0.2968)	(0.4006)
average temperature in Oct (mm)	-0.03674	-0.2097
	(0.2647)	(0.2404)
average temperature in Nov (mm)	0.3597	0.3073
	(0.2072)	(0.1830)
average temperature in Dec (mm)	0.3127	0.4584
	(0.1886)	(0.1958)
chemical fertilizer price index (base year is 1995)	0.00442	0.0213
	(0.0371)	(0.0298)
pesticides & appliance price index (base year is 1995)	0.0243	0.0374
	(0.0228)	(0.0231)
lagged corn production (10,000 tons)	0.0013	0.0010
	(0.0008)	(0.0007)
lagged wheat production (10,000 tons)	-0.0017*	-0.0014*
	(0.0007)	(0.0006)
lagged cassava production (10,000 tons)	1.0101***	1.0136***
	(0.0251)	(0.0256)
year		4.3145
		(2.1249)
p-value (Pr > F)	[0.0000]***	[0.0000]***
R-squared	0.9978	0.9980
# of observations	113	113

Notes: Robust standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 13. Vector Autoregression Results

Dependent Variable	Independent Variable	(1)	(2)	(3)
ethanol price (CNY/ton)	lagged ethanol price (CNY/ton)	-1.0172** (0.3240)	-0.7048*** (0.5677)	-1.6713** (0.6096)
	lagged corn price (CNY/50kg)	69.2566 (57.5811)	131.7903 (27.9488)	
	lagged wheat price (CNY/50kg)	57.2804 (47.5850)		123.2746*** (22.9831)
	lagged national 90# gasoline price (CNY/ton)		0.2494 (0.2812)	-0.4446 (0.2799)
	lagged number of provinces with E10 policy	-4.7508 (135.5469)	-280.2786 (220.1763)	412.0541* (199.1851)
	lagged ethanol subsidy (CNY/ton)	-0.8927 (0.6087)	-1.4610* (0.7436)	-0.0415 (0.6006)
corn price (CNY/50kg)	lagged ethanol price (CNY/ton)	0.0033* (0.0015)	0.01265*** (0.0031)	
	lagged corn price (CNY/50kg)	-0.4123 (0.2644)	1.0279*** (0.1515)	
	lagged wheat price (CNY/50kg)	1.3133*** (0.2185)		
	lagged national 90# gasoline price (CNY/ton)		0.0071*** (0.0015)	
	lagged number of provinces with E10 policy	4.0286*** (0.6224)	-3.2132** (1.1934)	
	lagged ethanol subsidy (CNY/ton)	-0.0045 (0.0028)	-0.0196*** (0.0040)	
wheat price (CNY/50kg)	lagged ethanol price (CNY/ton)	0.0023*** (0.0004)		3.9929*** (1.0665)
	lagged corn price (CNY/50kg)	-0.4766*** (0.0717)		
	lagged wheat price (CNY/50kg)	1.2576*** (0.0592)		- 233.5457*** (40.2077)
	lagged national 90# gasoline price (CNY/ton)			0.2151 (0.4896)

	lagged number of provinces with E10 policy	3.0621*** (0.1687)		-163.4265 (348.4637)
	lagged ethanol subsidy (CNY/ton)	0.0081*** (0.0008)		2.0708* (1.0507)
national 90# gasoline price (CNY/ton)	lagged ethanol price (CNY/ton)		2.1664* (1.0012)	3.9929*** (1.0665)
	lagged corn price (CNY/50kg)		-250.193*** (49.2892)	
	lagged wheat price (CNY/50kg)			-233.546*** (40.2077)
	lagged national 90# gasoline price (CNY/ton)		-1.0999* (0.4960)	0.2151 (0.4896)
	lagged number of provinces with E10 policy		1149.537** (388.2919)	-163.4265 (348.4637)
	lagged ethanol subsidy (CNY/ton)		4.7663*** (1.3113)	2.0708* (1.0507)
number of provinces with E10 policy	lagged ethanol price (CNY/ton)	0.0006 (0.0004)	0.0007 (0.0007)	0.0011 (0.0009)
	lagged corn price (CNY/50kg)	-0.0972 (0.0737)	-0.0645 (0.0348)	
	lagged wheat price (CNY/50kg)	0.0302 (0.0609)		-0.0541 (0.0328)
	lagged national 90# gasoline price (CNY/ton)		0.0008 (0.0004)	0.0004 (0.0004)
	lagged number of provinces with E10 policy	0.6754*** (0.1736)	0.5682* (0.2744)	0.2471 (0.2844)
	lagged ethanol subsidy (CNY/ton)	0.0008 (0.0008)	0.0006 (0.0009)	-0.0001 (0.0009)
ethanol subsidy (CNY/ton)	lagged ethanol price (CNY/ton)	-0.3002 (0.2014)	-0.4995 (0.3532)	-0.4034 (0.4148)
	lagged corn price (CNY/50kg)	31.1981 (35.7920)	-8.4015 (17.3874)	
	lagged wheat price (CNY/50kg)	-36.2692 (29.5785)		-9.8507 (15.6401)
	lagged national 90# gasoline price (CNY/ton)		-0.1588 (0.1750)	-0.1043 (0.1904)

lagged number of provinces with E10 policy	63.2145	238.26	188.4352
	(84.2550)	(136.9754)	(135.5461)
lagged ethanol subsidy (CNY/ton)	-0.1576	0.2035	0.1157
	(0.3784)	(0.4626)	(0.4087)

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 14. Granger Causality Results for Vector Autoregression Specification (1)

Equation	Excluded	P-value
ethanol price (CNY/ton)	corn price (CNY/50kg)	0.229
	wheat price (CNY/50kg)	0.229
	number of provinces with E10 policy	0.972
	ethanol subsidy (CNY/ton)	0.143
corn price (CNY/50kg)	ethanol price (CNY/ton)	0.029*
	wheat price (CNY/50kg)	0.000***
	number of provinces with E10 policy	0.000***
	ethanol subsidy (CNY/ton)	0.107
wheat price (CNY/50kg)	ethanol price (CNY/ton)	0.000***
	corn price (CNY/50kg)	0.000***
	number of provinces with E10 policy	0.000***
	ethanol subsidy (CNY/ton)	0.000***
number of provinces with E10 policy	ethanol price (CNY/ton)	0.119
	corn price (CNY/50kg)	0.187
	wheat price (CNY/50kg)	0.620
	ethanol subsidy (CNY/ton)	0.309
ethanol subsidy (CNY/ton)	ethanol price (CNY/ton)	0.136
	corn price (CNY/50kg)	0.383
	wheat price (CNY/50kg)	0.220
	number of provinces with E10 policy	0.453

Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 15. Granger Causality Results for Vector Autoregression Specification (2)

Equation	Excluded	P-value
ethanol price (CNY/ton)	corn price (CNY/50kg)	0.000***
	national 90# gasoline price (CNY/ton)	0.375
	number of provinces with E10 policy	0.203
	ethanol subsidy (CNY/ton)	0.049*
corn price (CNY/50kg)	ethanol price (CNY/ton)	0.000***
	national 90# gasoline price (CNY/ton)	0.000***
	number of provinces with E10 policy	0.007**
	ethanol subsidy (CNY/ton)	0.000***
national 90# gasoline price (CNY/ton)	ethanol price (CNY/ton)	0.030*
	corn price (CNY/50kg)	0.000***
	number of provinces with E10 policy	0.003**
	ethanol subsidy (CNY/ton)	0.000***
number of provinces with E10 policy	ethanol price (CNY/ton)	0.309
	corn price (CNY/50kg)	0.064
	national 90# gasoline price (CNY/ton)	0.829
	ethanol subsidy (CNY/ton)	0.533
ethanol subsidy (CNY/ton)	ethanol price (CNY/ton)	0.157
	corn price (CNY/50kg)	0.629
	national 90# gasoline price (CNY/ton)	0.364
	number of provinces with E10 policy	0.082

Significance codes: * 5% level, ** 1% level, *** 0.1% level.

Table 16. Granger Causality Results for Vector Autoregression Specification (3)

Equation	Excluded	P-value
ethanol price (CNY/ton)	wheat price (CNY/50kg)	0.000***
	national 90# gasoline price (CNY/ton)	0.112
	number of provinces with E10 policy	0.039*
	ethanol subsidy (CNY/ton)	0.945
wheat price (CNY/50kg)	ethanol price (CNY/ton)	0.000***
	national 90# gasoline price (CNY/ton)	0.000***
	number of provinces with E10 policy	0.047*
	ethanol subsidy (CNY/ton)	0.002**
national 90# gasoline price (CNY/ton)	ethanol price (CNY/ton)	0.000***
	wheat price (CNY/50kg)	0.000***
	number of provinces with E10 policy	0.639
	ethanol subsidy (CNY/ton)	0.049*
number of provinces with E10 policy	ethanol price (CNY/ton)	0.212
	wheat price (CNY/50kg)	0.099
	national 90# gasoline price (CNY/ton)	0.337
	ethanol subsidy (CNY/ton)	0.884
ethanol subsidy (CNY/ton)	ethanol price (CNY/ton)	0.331
	wheat price (CNY/50kg)	0.529
	national 90# gasoline price (CNY/ton)	0.584
	number of provinces with E10 policy	0.164

Significance codes: * 5% level, ** 1% level, *** 0.1% level.