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Bioethanol development in China and the potential impacts on its agricultural economy

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ABSTRACT

China is now the third largest bioethanol producer in the world after the United State and Brazil. The overall goals of this paper are to provide an overview of China's current bioethanol program, its future trend, and the likely impacts on its agricultural economy in the future. The analysis shows that China has developed an ambitious long-run biofuel program with a series of financial and institutional supports. While there are several potential feedstock crops available for bioethanol production, lack of land for feedstock production is one of major constraints in China's bioethanol expansion. The results show that although China's bioethanol expansion will have little impacts on overall agricultural prices in international markets, it will have significant impacts on the prices, productions, and trade of those energy crops being used for bioethanol production in China.

1. Introduction

China's economy has experienced remarkable growth since economic reforms initiated in 1978. Annual average growth rate of gross domestic product (GDP) reached nearly 10% in the last three decades. The rapid growth of China's economy also led to a rapid rise in demand for energy that also gave rise to mounting concerns in the country about its national energy security. The nation's record on greenhouse gas emission is also becoming a concern not only in China but the rest of the world as well. In 2007, China's net import of oil has reached to 186 million tons, accounting for 49.6% of its total oil demand [17].

Given the energy security concerns, the search for alternative sources of energy has become a top policy priority of the Government of China. Biofuel, with its reputation of being relatively carbon neutral, has been the center of much attention by the Government [2]. China is now the third largest bioethanol producer in the world after the United States and Brazil, with annual production of bioethanol production of 1.35 million tons in 2007 [11].

Rising bioethanol production in China also has raised several issues to be analyzed and assessed. What has been the trend of China's bioethanol production? What are the major policies that have supported its bioethanol program? If China wants to expand its bioethanol production in the future, what are the appropriate feedstock crops? What is the bioethanol production potential of China given its limited resources? And how China's bioethanol expansion in the future will affect its agricultural price, production, and national food security? Answers to these questions are critical important as China are developing its long term plan and target for bioethanols.

Although there are a few studies on the potential impacts of bioethanol development on agricultural economy in developed countries, little study is availably for China, Kojima and Johnson [12] United Nations [23]. A study by Shapouri [19] showed that the development of bioethanol in the US will have big impact on the production structure of US, with more land expected to be drawn towards maize production and the proportion of land under wheat and other crops production will decline. IFPRI [8] showed that if the world major biofuel producing countries expanded their biofuel production based on their current "first-generation bioethanol technologies" and future targets, it will significantly increase world prices of feedstock crops as well as other agricultural commodities. Biofuel development can also have significant impacts on the structure and distribution of agricultural production, agricultural trade, poverty, and the welfare of different household [1,18,22,24]. Although farmer's income is expected to increase generally due to the rise of agricultural production and price, the distribution seems unlikely to be equal. Farmers with more energy crop intensified farming resources may

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Table 1
Distribution and feedstock use of bioethanol plants in China in 2007.

Location	Yield (thousand ton/year)	Feedstock	Feedstock demand (thousand ton/year)
Jilin	600	Maize	1820
Heilongjiang	100	Maize	330
Henan	300	Wheat/maize	900
Anhui	320	Maize	960
Guangxi[a]	200	Cassava	1440

Source: Chinese Academy of Agricultural Engineering [3].
[a] Operation of the cassava-based bioethanol plant in Guangxi was scheduled to start in early 2008; hence, yield and feedstock demand were estimated based on its production capacity.

gain more than those without. On the consumption side, net buyers of agricultural commodities may suffer because of the rise in food prices [6].

The overall goals of this paper are to provide an overview of China's current bioethanol program, its future trend, and the likely impacts on its agricultural economy in the future. To achieve these goals, the paper is organized as follows. Section 2 discusses China's current biofuel production, policies and future targets. Section 3 examines the feedstocks that can be used for bioethanol production in China, and explores China's land potentials on bioethanol expansion in the future. Based on the discussions on China's bioethanol policies, potential feedstocks and marginal land in Sections 2–4 formulates different scenarios of China's bioethanol development and analyzes the potential impacts of China's bioethanol expansion on its agricultural price, production, and national food security. The final section concludes this study.

2. China's biofuel development and major policies

2.1. Biofuel production in China

China's biofuel industry has expanded rapidly since early 2000s. Bioethanol production reached 1.35 million tons in 2007. Four large-scale state-owned bioethanol plants in Heilongjiang, Jilin, Henan, and Anhui provinces were constructed in 2001. The total annual bioethanol production capacity of these four plants, which mainly use maize as feedstock, is approximately 1.5 million tons. In 2007, China set up another bioethanol plant based on cassava in Guangxi Province, which started operation in early 2008. The annual production capacity of this plant in the initial stage is 0.2 million tons. Table 1 shows the distribution of China's five bioethanol plants and their feedstock demands in 2007. Currently, E10 (gasoline mixed with 10% ethanol) was used in the transport sector in the five provinces (Heilongjiang, Jilin, Liaoning, Anhui, and Henan) and 27 cities in Jiangsu, Shandong, Hubei and Hebei provinces.

China has also been promoting biodiesel production though the total production is still small. By the end of 2007, there were about 10 biodiesel plants operating in China. Most of them use industrial waste oil and waste cooking oil as feedstock. The total annual production capacity for all of these plants is less than 0.2 million tons. Biodiesel production needs a stable supply of lipid or vegetable oil as feedstock, but China is short of those feedstocks. In 2007, China imported more than 30 million tons of vegetable oil for food consumption. Given the domestic supply constraints, China is planning to develop forestry-based biodiesel, particular that based on jatropha seeds. Also, because the production of biodiesel in China is still very small, there is no national standard for biodiesel yet. Most of the biodiesel was used in the local transport sector and in some industry companies as a substitute for diesel fuel.

2.2. Policies and targets of China's biofuel production

In order to facilitate bioethanol production and marketing, China has set up a series of supporting policies since the late 1990s. In the initial years, substantial support was given through investment in R&D and technology development. The Special Development Plan for Denatured Fuel Ethanol and Bioethanol Gasoline for Automobiles in the 10th Five-Year (2001–2005) Plan were announced in early 2001. The main goal of the Plans was to experiment with bioethanol production, marketing, and support measures. To achieve this goal, two policy documents, namely, the Pilot Testing Program of Bioethanol Gasoline for Automobiles and Detail Regulations for Implementing the Pilot Testing Program of Bioethanol Gasoline for Automobiles, were jointly issued by the National Development and Reform Commission (NDRC) and seven other relevant ministries in early 2002 [16]. In the meantime, national standards for denatured fuel ethanol and bioethanol gasoline for automobiles were formulated and implemented. The marketing of a bioethanol and gasoline blend with 10% ethanol (E10) for the automobile sector was initiated in three cities in Henan Province and in two cities in Heilongjiang Province in 2003.

These two policy documents specified the following major support policies during the implementation of the pilot testing program. First, the 5% consumption tax on all bioethanols under the E10 program was waived for all bioethanol plants. Second, the value-added tax (normally 17%) on bioethanol production was refunded at the end of each year. Third, all bioethanol plants received subsidized "old grain" (grains reserved in national stocks that are not suitable for human consumption) for feedstock.[1] This subsidy is jointly provided by the central and local governments. Fourth, a subsidy was offered by the central government to ensure a minimum profit for each of bioethanol plants. That is, if despite all three support mechanisms described above, any bioethanol plant were to record a loss in the production and marketing of bioethanol, it would receive a subsidy from the Government that equals the gap between marketing revenues and production costs plus a reasonable profit that the firm could have obtained from an alternative investment. This subsidy is estimated for each plant at the end of each year. Besides these four support policies, the Government of China also ensured markets for the bioethanols produced by these state-owned plants. Bioethanol produced by private plants was not allowed to enter the market.

With the experience gained from the first phase of testing, China expanded its pilot testing program in 2004. New policy guidelines on the expanded pilot testing program were issued in early

[1] After the "old grains" had been exhausted since 2005, those existing four plants have been using regular maize either bought from grain companies or directly from the farmers. But the expansion of production capacity of these plants will have to base on non-grain feedstock.

2004 and replaced the ones previously issued in early 2002[2]. The new policies proposed the expansion of bioethanol production in four plants set up in early 2000s. Annual bioethanol use in automobiles was targeted at 1.02 million tons in 2004. Five provinces and 27 cities in another four provinces were selected to participate in the second phase of expanded testing. The new policy guidelines also ensured that most supporting policies implemented in the first phase of pilot testing would continue into the second phase of pilot testing, with the exception of the measure that ensured a minimal level of profit. In the second phase, in order to encourage technological innovation and provide incentives for improving efficiency of bioethanol production, a fixed amount of subsidy has been provided to all bioethanol plants. The level of this fixed subsidy is computed based on the average production cost of biofuels per ton from all biofuel plants rather than the specific production cost of each plant.

In 2005, China issued the Renewable Energy Law, making it clear that China will forcefully push the development of renewable energy including biofuels. In June 2007, under the guidelines stipulated by the Renewable Energy Law, NDRC formulated the Middle and Long Term Development Plan of Renewable Energy**.** According to this plan, the annual bioethanol and biodiesel production is targeted at 10 and 2 million tons by 2020, respectively. In 2007, a set of supporting policies that will be jointly implemented by NDRC, the Ministry of Finance, and several other relevant ministries were also announced. The new supporting policies are similar to those implemented in the second phase of pilot testing, but with the following revisions. First, the previous fixed profit/loss subsidies are replaced by a new measure called "flexible subsidy for loss." Recognizing the existence of oil market price fluctuations, a Risk Fund has been developed to smooth the shocks from oil price changes. The subsidy level is flexible as it is linked to gasoline market prices. Second, a new subsidy will be granted to firms that develop a new production base of feedstock not currently produced in the existing cultivated land area. This policy is in response to recent increasing concerns regarding the trade-off between food (grain) security and energy security. The Government has announced in 2007 that, except for the four existing maize and wheat bioethanol plants, cereal, including maize and wheat, will no longer be allowed for use as bioethanol feedstocks, and the four existing plants are prohibited from expanding any capacity for utilizing cereal as a feedstock to produce bioethanol. Third, some government supports for operations are offered to large bioethanol plants that provide demonstration services in processing technology and marketing for other bioethanol plants, including private and state-owned plants.

3. Feedstocks and potentials of China's bioethanol productions

3.1. Potential feedstocks for China's bioethanol production

3.1.1. Maize and wheat

In the testing and demonstration stage, China continues to utilize first-generation technology to convert grain into bioethanol. These materials are saccharified and fermented before being converted into ethanol. Prior to 2005, three large plants using maize to produce bioethanol were established in three major maize-producing provinces (Heilongjiang, Jilin, and Anhui). To reduce the reserve costs and dispose of the rotting wheat, China also built another ethanol plant using wheat as feedstock in Henan Province in 2003. However, after 2004, the "old" maize and wheat had been used up, and with the prospect of limited supplies of maize and wheat grain available for bioethanol production, China has begun experimenting with the use of "non-grain crops" to produce bioethanol [14].[3] With growing concerns over the impacts of biofuel expansion on food security, China has disallowed the use of grain for future expansion of biofuel production since 2007. China has recently indicated that it will expand its biofuel target using cellulosic feedstocks in the future [15]. However, significant research on these second-generation technologies is still in the planning stages.

Table 2
Production of major feedstocks in China in 2006.

	China		
	Area (1000 ha)	Yield (kg/ha)	Production (1000 ton)
Maize	26970.8	5394	145,485
Wheat	22961.6	4550	104,464
Sorghum	566.4	3704	2098
Cassava[a]	438	20	8760
Sweet potato[b]	4913.2	3905	19,185
Sugarcane	1495.4	66,727	99,783,667

[a] Data for cassava are from development office of sub-tropical crops, Ministry of Agriculture of China.
[b] Sweet potato area (or production) data are estimated by the total tuber crop area (or production) minus potato area (or production).

3.1.2. Sweet sorghum

Sweet sorghum is considered as the most important feedstocks to be used in bioethanol production in China in the future. China has launched research and pilot production activities on sweet sorghum, especially on alkaline and saline lands, as a feedstock for bioethanol production. Although sweet sorghum production is currently limited, it is likely that China will increase sweet sorghum production, at least in the short run, as one of its principal feedstocks for bioethanol production. In 2006, total production of sorghum, which is a very minor crop compared with rice, maize, and wheat, amounted to 2098 tons (Table 2). Currently, most of the sorghum produced in China was used for alcohol production.

Sweet sorghum has high tolerance to drought and water logging, and can be planted on saline-alkali soils [4]. It can be cultivated in areas with temperature that is above 10 °C (preferably less than 40 °C). Many provinces in China are suitable for sweet sorghum production. The most suitable cultivation areas are in Northeast China, North China, Northwest China, and some areas of the Huanghuai River Delta. Sweet sorghum is also a crop with high energy content, high photosynthesis efficiency and high biomass production capacity. Sweet sorghum has high biomass output, with grain yield of 14–27 kg/ha and its fresh stem yield can reach about 200–300 kilograms per ha Simpson et al. [20]. The stem of sweet sorghum has high sugar content, which could be used for bioethanol production through simple fermentation.

3.1.3. Cassava

Because of its high yield and high ethanol conversion rate, cassava has been considered by China's leaders as the second most important bioethanol feedstock. The newly established cassava-based bioethanol plant in Guangxi Province with a targeted annual bioethanol production capacity of 200 thousand tons has started operation in 2008.

Cassava, a perennial sub-shrub, is one[4] of the three largest tuber crops in the world Wang et al. [25]. Its high yield of biomass on per unit of land, high tolerance to drought and barren land, and high starch content make cassava suitable for use as feedstock for bioethanol production [21]. In 2006, the total area planted to cassava was

[2] The two documents, the expanded pilot testing program of bioethanol gasoline for automobiles and the detail regulations for implementing expanded pilot testing program of bioethanol gasoline for automobiles were jointly issued by NDRC and seven other relevant ministries.

[3] "Non-grain crops", a special term used in biofuel program in China, means all crops or plants except for rice, wheat and maize.

[4] The other two large tubers are the potato and sweet potato.

438 thousand ha, with a total output of 8.76 million tons (Table 2). Currently, cassava is mainly used for starch and ethanol production in China. Major cassava-producing areas in China are Guangxi, Guangdong, and Hainan. The total output of these three provinces accounts for more than 90% of total cassava output in China. Guangxi is the largest cassava-producing province in China. Area and production of cassava in Guangxi accounted for 62% and 65% of national total, respectively, in 2005 Yang et al. [27].

3.1.4. Sweet potato

Sweet potato is grown in most provinces in China and is also considered policy makers as one potential source of feedstocks for bioethanols though it will play much minor role than sweet sorghum and cassava. In 2006, sweet potato production area in China totaled 4.9 million ha, with a total output of 19.2 million tons (Table 2). Major production provinces include Sichuan, Henan, Chongqing, Shandong, Guangdong, and Hebei, whose combined total output accounted for more than 60% of China's total sweet potato production. Sweet potato is mainly used for processed food, feed, and feedstock for alcohol production. It also has a high biomass yield. Average yield of fresh sweet potato is 0.13–0.33 tons/ha, and the starch content of fresh sweet potato is about 18–30%. With the current technology, about 8 tons of fresh sweet potato can produce 1 ton of ethanol.

3.1.5. Sugarcane

Sugarcane is also the other potential feedstock for bioethanol in China, however, it is not likely that sugarcane will become important feedstock to produce ethanol in the future. Sugarcane area in 2007 reached 1.5 million ha, with sugarcane production of 99.8 billion tons (Table 2). Guangxi, Yunnan and Guangdong are the major sugarcane production provinces, accounted for 86.4% of China's total output in 2007. Under current technology, 13.3 tons of fresh sugarcane can produce 1 ton of bioethanol. However, China is a sugar importer. Its import was about 1.19 million tons in 2007, about 10% of China's total sugar demand, MOA. Moreover, sugar import has been rising and is projected to continue to rise in the future [7]. Given this situation, in the impact assessment presented in Section 4, we do not consider using sugarcane as feedstock for bioethanol production.

3.2. Cost and productivity of different feedstocks for bioethanol production

Under current feedstock production and biofuel processing technologies, there are large variations in the productivity of land in producing biofuel. Tian and Zhao [21] showed that, on average, per hectare of land can produce 19.5 tons of fresh cassava, 24.2 tons of sweet potato, 60 tons of sweet sorghum, about 64 tons of fresh sugarcane, 5.29 tons of maize, or 4.28 tons of wheat. Using the current bioethanol production/processing technology, per hectare of land can produce 2.87 tons of ethanol based on cassava, 3.92 tons of ethanol based on sweet sorghum, 4.81 tons of ethanol based on sugarcane, or 1.87 tons of ethanol based on maize. The figures indicate that bioethanol productivity is highest from sugarcane.

However, the results on the cost of production show that given the current technologies and feedstock prices, cassava, sweet sorghum, and sweet potato are the most viable crops for feedstocks. Using the feedstock price of 2006, for every ton of bioethanol production, cassava-based bioethanol production is estimated to have the lowest feedstock costs, which is about 2400 yuan (about US$354), followed by sweet sorghum, sweet potato, sugarcane, maize, and wheat, in that order [21]. It should be noted that although cassava, sweet sorghum, and sweet potato are relatively cheaper to produce ethanol, their prices will rise with the future expansion of ethanol production using these crops as feedstocks Yang et al. [27]. More careful study is needed to investigate the impacts of ethanol production on the prices of various crops under different feedstock scenarios.

As the costs of using maize and wheat as feedstocks in China are high, large government subsidies are required to produce ethanol. If feedstock cost accounts for 60% of ethanol production cost (according to the authors' interview), the results presented in Table 3 suggest that the cost of ethanol production could reach as high as 5600 yuan/ton for maize-based ethanol and 7650 yuan/ton for wheat-based ethanol. The Government required that bioethanol plants should be able to sell their fuel ethanol to an appointed oil company, such as Sinopec or PetroChina, at a price of 0.9111 of the price of 90# gasoline (about US$0.82 per liter) in 2008. The gap between the sale price and production cost will have to be covered by government subsidy. In August 2005, the Ministry of Finance of China issued a document that regulated the subsidy level of bioethanol at 1883, 1628, 1373 and 1373 yuan per ton for the years from 2005 to 2008, respectively.

3.3. Potential lands for biofuel production in China

With the rapid expansion of global biofuel production, the world as well as China's food prices rose rapidly over 2007 and 2008 that threatened the Government's food security goal. To reduce the stress on food security, China has prohibited the use of grain (maize and wheat) for biofuel production starting in 2007 and instead promoted the use of sweet sorghum, cassava, sweet potato, and other non-cereal grain crops as major feedstocks. The new policy also emphasizes that these non-cereal grain feedstocks should only be produced on marginal lands. While well intentioned, many people doubt if these policies can effectively be implemented. The success of these policies depends on the availability of agricultural resources, especially marginal lands, to produce the non-grain feedstocks.

China has very limited marginal arable lands with potential for energy crop production. Moreover, these potential arable lands are usually fragmented. According to the survey conducted in 2003–2004 by the Ministry of Land and Resources [13] and a recent study

Table 3
Distribution of potential reclaimable arable land (1000 ha).

Region	Reclaimable grassland	Reclaimable saline areas	Reclaimable mudflat	Other reclaimable	Total
Northeast China	214.6	142.0	62.5	9.7	428.8
North China	190.2	141.2	124.5	47.5	503.4
Loess Plateau	47.91	12.03	2.86	17.63	80.43
Northwest	1933.7	341.1	28.1	1360.8	3663.7
Middle and East China	336.4	5.4	227.6	62.2	631.6
South China	62.1	0.4	51.1	6.4	120.0
Southwest China	237.1	0.2	22.5	35.2	295.0
Qingzang Plateau	162.6	49.9	2.3	12.5	227.3
Total	3615.8	800.5	547.2	1710.6	6674.3

Source: Ministry of Land and Resources of China [13].

Table 4
Distribution of suitable arable lands for energy crop in different regions (1000 ha).

Region	Energy crop	2012	2020
Northeast China	Sweet sorghum	86	214
North China	Sweet sorghum, sweet potato	101	252
Loess Plateau	Sweet sorghum, sweet potato	161	402
Inner-Mongolian and Xinjiang	Sweet sorghum	733	1832
Middle and lower Yangtze River	Cassava, sweet sorghum	126	316
South China	Cassava	24	60
Southwest China	Sweet potato	59	148
Qingzang Plateau	None	0	0
Total		1290	3220

Sources: Ministry of Land and Resources of China [13]; Tian and Zhao [21].

conducted by the Chinese Academy of Agricultural Engineering [3], the total of potential large-scale arable land was estimated at 6.7 million ha, or about 8.27% of total reserved land (Table 3). These are reclaimable areas but their full use for cultivation is still hindered especially when effects on ecosystem services are taken into consideration.

Reclaimable arable lands for different energy crop are presented in Table 3. This originated from a recent study conducted by the Chinese Academy of Agricultural Engineering to examine the distribution by region of suitable arable lands for energy crops [3]. In that study, they estimated potential reclaimable arable land in China by each region. The results show that China has about 6.67 million hectare of potential reclaimable land and distributed overall China, particular in Inner Mongolia and Xinjiang (the last column, Table 3). After considering ecological environmental protection, urbanization, the compatibility of energy crops, and technology improvement for feedstock production, it assumed that about 20% and 50% of potential reclaimable arable land could be considered as suitable arable lands for energy crop in 2012 and 2020, respectively. Based on the above assumption, it is estimated that there will be about 1.29 million hectares in 2012 and 3.22 million hectares in 2020 that can be used for energy crop production (Table 4).

The estimates on suitable arable lands for ethanol energy crop indicate that while there is less potential for a large-scale expansion of the biofuel industry in China. For example, even if all suitable arable lands for energy crop presented in Table 4 could be reclaimed and used in energy crop production in 2020, these lands would account for only 2.5% of current cultivated land (130.04 million hectares). It is important to note that bringing this land into production would also require substantial investment, and the large spatial distribution of these lands will present a great challenging to the transportation of feedstocks for processing.

3.4. Potentials for bioethanol production in China

Given the limit amount of potential land available for ethanol energy crop production, the issue which we are interested in is whether or not the estimated suitable arable lands are enough to produce feedstocks to meet target biofuel production in 2020. The production potentials for bioethanol can be estimated by the suitable arable lands for energy crop, the yield of energy crops, and the conversion rate of feedstocks to biofuels Wang et al. [25]. Taking into account the low quality of reclaimable marginal land and likely improvement of crop production technology [10], we assume that future crop yields on marginal land will be 20% lower than yields obtained in current cultivated land. We further assume that producing 1 ton of bioethanol requires 7 tons of cassava, 16 tons of sweet sorghum, or 8 tons of sweet potato. Based on the above assumptions, it is estimated that, at the maximum, China can produce about 5 million tons of ethanol by 2012 from 1.29 million hectares of marginal land planted to cassava, sweet sorghum, and sweet potato. If this trend will continue, bioethanol production could reach 12 million tons by 2020, assuming there will be 3.32 million hectares of marginal land used for cassava, sweet sorghum, and sweet potato production. It should be noted that these production potentials are based on optimistic estimations, which do not take into consideration of water resource constraint, suitability of soil quality for those feedstock crops, and cost effectiveness of planting feedstocks on those marginal lands. In real situation, bringing half of these marginal lands into farming is already a challenge task for China to achieve.

4. Potential impacts of China's bioethanol development on its agricultural economy and food security

Previous section shows that the room to expand China's bioethanol is not substantial but moderate. Although there is strong support and great optimism among China's policymakers for the development of ethanol production from non-cereal feedstocks produced from marginal lands, however, the previous studies and our analysis show that, under the first-generation of bioethanol production technologies, China can reach its current bioethanol production target only when we consider all potential non-cereal feedstocks and potential marginal lands would be used for bioethanol production in the future.

Several obstacles must be overcome before non-cereal-based and marginal land based ethanol production can play a significant role in China's fuel supply.[5] First, the cost to reclaim those marginal lands could be very high. If there were no substantial subsidy from the government, farmers will have very low incentives to invest on marginal land reclamation. Second, difficulties associated with collecting and transporting feedstock from the field to ethanol plants can be a big challenge. Most non-cereal feedstocks are bulky and difficult to ship long distances, given that a large share of China's marginal croplands lies in remote and mountainous locations. Third, the land quality of these marginal lands is much lower than the cultivated land, and the availability of water resource for those marginal lands is also a critical issue, so whether those lands can be fully used for feedstock production is questionable. Even they can be reclaimed and be used for feedstock production, the yield of those land will be considerably low. Because of these challenges, it will be difficult for the government to monitor that all feedstocks were produced from marginal lands. Farmers have the rights and incentives to produce feedstocks on their own cultivated lands if it's profitable. In this section, we will explore the potential impacts of China's bioethanol expansion on its future agricultural economy if only part or no feedstocks were produced on marginal lands.

[5] These obstacles were based on our personal interviews with persons from four bioethanol processing plants and experts on land resources and bioethanol technology from Chinese Academy of Sciences.

4.1. Methodology and scenarios

To understand the likely impacts of China's bioethanol development on its agriculture economy and food security, an analytical framework has been set up based on the Global Trade Analysis Project (GTAP) platform.[6] Because GTAP is a global trade model, we can track the impacts of China's bioethanol development on food import and export and therefore national food security, and also because the model is a general equilibrium one, it is possible to analyze the linkages between biofuels and agricultural markets, and to analyze the competing use of different commodities, such as the competing use of maize as feed and biofuel feedstock. Since the prices are used to balance the supply and demand of all commodities in the model, which means commodity prices are endogenous, the model can also trace the impacts of price changes on the production and consumption of each commodity. To make the standard GTAP modeling platform more suitable for this analysis, several modifications were made. First, because the GTAP database does not have a biofuels sector, the production activities that produce biofuels are created and added into the GTAP as a separate sector. Second, agriculture is linked with energy markets through biofuel sectors. A set of parameters is added to capture the substitution between biofuels and gasoline. Third, we also made efforts in refining and determining elasticities of substitution in land allocation among different crops.

Three scenarios were developed: one reference scenario (S0) and two alternative bioethanol scenarios. The main aim of this analysis is to assess the impacts of China's bioethanol development on its agricultural production, price, and trade. The reference scenario is constructed to reflect a counter fact situation for later comparison. This scenario have the following four major assumptions: (1) bioethanol production in China in 2007–2020 would not be expanded beyond its production level in 2007 (1.35 million ton); (2) there would be no new marginal land be used for feedstock production; (3) all bioethanol would be produced from maize and (4) there would be no improvement in the yield of feedstock crops (row 1, Table 5).

The first alternative bioethanol scenario (S1) is designed to examine the impacts of bioethanol development if the feedstocks would be diversified and some marginal land would be introduced to produce these feedstocks. Specifically, we made the following major assumptions in this scenario based on the discussions in Sections 2 and 3. On the top of reference scenario, we assume that China's bioethanol targets (10 million tons) in 2020 would be reached with 50% of the non-grain feedstocks be produced from the marginal land.[7] We applied 50% instead of 100% because there are several obstacles to expand crops in marginal land discussed above. Amount of feedstocks from maize will be kept the same as that under the reference scenario, which will produce about 14% of target biofuel production in 2020. The rest of bioethanol production would come mainly from sweet sorghum (50%) and cassava (30%), partly from sweet potato (6%) in 2020 (row 2, Table 5). Assumptions of more feedstocks from sweet sorghum (50%) and cassava (30%) than sweet potato and no feedstocks from sugarcane are consistent with potential feedstocks and costs of feedstock to produce bioethanols discussed in Sections 3.1 and 3.2 as well as government policy discussed in Section 2. For parameters of converting rates from feedstocks to bioethanol, we use the parameters presented in Table 1, which were discussed in Section 3.

Because the expansion of bioethanol and feedstock production, we expect that there will be increase in research and development investment in these new feedstock crops and therefore we assume that the yield of these crops will be improved by 30% in 2020 (comparing with the reference scenario, rows 1 and 2).

The second alternative scenario (S2) is designed to assess the likely impact of increasing marginal land for bioethanol development. On the top of S1, this scenario assumes that there would be no new marginal land to be introduced to produce feedstocks (row 3, Table 5). Other assumptions in this scenario, such as converting rates from feedstock to bioethanol, component of feedstocks, and non-maize feedstock crop yield improvement, are the same as the assumptions in scenario 1 (S1). The impacts of marginal land can be assessed by comparing the results between S1 and S2.

4.2. Impacts of China's bioethanol expansion

Biofuel development in China will have significant impacts on the prices of the feedstocks. Our simulations show that if China wants to fulfill its bioethanol development target in 2020 with 50% of non-cereal feedstock be produced from marginal land, it will increase the prices of cassava and other grains (including sorghum, sweet potato and other minor cereals) by 26.26% and 22.24%, respectively (Table 6).[8] If all the feedstocks were not produced on the marginal land, it will raise the prices of cassava and other grains by 55.88% and 47.32%, respectively. Although the results show that there will be also some positive impacts on the prices of non-feedstock products, the impacts are very minor (Table 6). For example, if half non-grain feedstocks were produced on arable land, China's maize, wheat, and rice prices will increase 0.26, 0.18, and 0.13%. The positive impact on other agricultural product prices is because the increase in feedstock production will take some land and other agricultural production resources (e.g., agricultural labor) from other agricultural sectors and reduce the supply of other agricultural commodities. The extent to which other agricultural commodity prices will increase depends on the nature of substitution between the production of those commodities and feedstocks. The increase in maize and other crops' prices will also increase the cost of livestock production. Under S1 and S2, all the prices of livestock products will increase though at a very moderate rate.

The projected increase in the prices of the major feedstocks will trigger significant increases in the production of these commodities. Table 6 shows that the production of cassava and other grains will increase by 162.36 and 43.78%, respectively, under S1 compared with the results under reference scenario in 2020 (Table 6). The productions of cassava and other grains will increase at even higher rates if no marginal land be used to produce feedstocks because of the higher prices in S2 than in S1. The increase of the feedstock production is at a slight cost of other agricultural production. For example, maize production will decrease about 0.46% under S1, and decrease 1.02% under S2. The bioethanol production will also have slight negative impacts on livestock production (Table 6). For example, pork and poultry production will decrease by 0.68% under S1 and 1.51% under S2. It is not only because more agricultural production resources will move out from livestock sector to feedstock sectors due to relative input and output price changes, but also because the increase of livestock products will lower consumers' demands for livestock products. The results of our analysis also show that if China is going to mainly use sweet

[6] GTAP is a well known multi-country, multi-sector computable general equilibrium model, details of this model can be found in Hertel [5].

[7] According to our discussion in Section 3, if all potential marginal lands for bioethanol feedstock production analyzed in the previous section would be reclaimed, China could produce its targeted level of bioethanol in 2020 based on these marginal lands. However, as mentioned earlier, it will be too optimistic to assume all these potential lands can be brought into feedstock crop production. Therefore, we assume that there will be about 50% of the non-grain feedstocks to be produced from the marginal land.

[8] We are not able to separate sorghum, sweet potato and other minor cereals into individual sectors in GTAP current database, therefore we analysis the impacts for all these grains together.

Table 5
Key assumptions under three simulation scenarios.

	Bioethanol output in 2020 (million ton)	Utilization of new marginal lands	Component of feedstocks	Non-maize feedstock crop yield improvement
Reference scenario	1.35	No new marginal and be used	Maize (100%)	No improvement
Bioethanol scenario 1	10	Half of the non-cereal feedstocks produced on new marginal land	Sweet sorghum (50%); Cassava (30%); Sweet potato (6%); Maize (14%)	30% higher
Bioethanol scenario 2	10	No new marginal land be used	Sweet sorghum (50%); Cassava (30%); Sweet potato (6%); Maize (14%)	30% higher

Table 6
Impacts of China's bioethanol development on agricultural price, production, and food security in China.

	Impacts (%) of scenario 1 (S1) compared with S0			Impacts of scenario 2 (S2) compared with S0		
	Price	Production	Self-sufficiency level	Price	Production	Self-sufficiency level
Rice	0.13	−0.14	0.00	0.28	−0.30	0.00
Wheat	0.18	−0.18	0.00	0.39	−0.40	−0.01
Maize	0.26	−0.46	−0.35	0.55	−1.02	−0.83
Other grains	22.24	43.78	−28.69	47.32	95.75	−60.41
Cassava	26.26	162.36	−21.33	55.88	345.14	−44.90
Vegetables and fruits	0.15	−0.27	0.00	0.31	−0.60	0.00
Soybean	0.04	−0.20	−0.01	0.09	−0.44	−0.03
Other oilseeds	0.07	−0.16	−0.01	0.15	−0.32	−0.02
Sugarcane	0.19	−0.04	−0.01	0.41	−0.09	−0.03
Fibers	0.06	−0.43	0.00	0.12	−0.95	0.00
Other crops	0.04	−0.14	0.00	0.09	−0.31	−0.01
Beef and mutton	0.01	−0.25	0.00	0.02	−0.53	0.00
Pork and poultry	0.04	−0.68	−0.01	0.08	−1.51	−0.02
Milk	0.05	−0.36	−0.03	0.11	−0.81	−0.07

Note: other grains include sweet potato and cereals excluding rice, wheat and maize (e.g., sweet sorghum, millet, barley, oats, etc.).
Source: results of authors' simulation.

sorghum, cassava and sweet potato as feedstocks, there will be substantial financial implications of promoting a large-scale bioethanol program in the future because the prices or costs of feedstocks will rise substantially with the expansion of bioethanol production.

It is interesting to note that bioethanol development in China will have only very small impacts on its food security except for those commodities used as feedstocks. Here, we use food self-sufficiency level, share of net import in total demand, as an indicator for food security at national level. This is not surprising because China's bioethanol development will highly depend on "non-grain" crops. The results in Table 6 show that under alternative scenario 1, the impact of bioethanol on maize self-sufficiency will be about −0.35% and the impacts will be almost zero for all other non-feedstock products (Table 6). Even under alternative scenario 2, the negative impacts on net import (import minus export) of most non-feedstock products will be still less than 0.05% except for maize whose self-sufficiency will be 0.83% lower. However, the self-sufficiency levels of China's cassava and other grains will decrease by 44.90 and 60.41%, respectively, in 2020.

We would also like to note that the results presented in this paper should be interpreted cautiously due to several limitations that have prevented the analysis of impacts of the bioethanol program in a more comprehensive way. One of the major limitations in the analysis is the imposition of half of the non-cereal feedstocks produced on new marginal land in scenario 1 and likely yield improvement in feedstock crops under scenarios 1 and 2. If all additional feedstock would be produced in marginal land and yield improvement would be much higher than 30% in 2020 as we assumed, the impacts of bioethanol expansion on agriculture would be much less than what we have presented above. On the other hand, the impacts would be higher if there would be less marginal land available for feedstock crop production and less progress in crop yield improvement. However, we believe that if we consider the likely environmental implications of bringing large marginal land into crop production and costs of reclaiming the marginal land, we might be not tend to assume huge marginal land to be reclaimed in the future. While two alternative scenarios formulated are not intend to present actual situation in 2020, the simulation results from these scenarios can give a general perspective on how the expansion of China's bioethanol development will have impacts on its agricultural production, agricultural price, and food security.

5. Concluding remarks

The rapid growth of China's economy has raised serious concerns over the nation's energy security. Despite the rapid growth of domestic energy production, demand has grown even faster. China has shifted from being a net energy exporter to being an importer since the late 1990s and is becoming one of the largest importers in the world in recent years. The major rise in energy import has come from the increased oil demand in transportation. Most projections show that about 60–75% of China's oil demand will have to be met by import in 2020 [9]; Wei et al. [26].

In dealing with the challenges ahead, China has prepared its long-run biofuel development plan and a series of supporting policies associated with the plan. Meantime, with the rising concerns over the impacts of biofuels on the national grain security, China has decided to shift from maize and wheat-based to a "non-grain crops" based bioethanol program and planned to use marginal land for feedstock production. The prioritized and potential crops for feedstocks include sweet sorghum, cassava, and sweet potato. Given the current prices and technologies, cassava is the most viable crop for feedstocks. While there are still potential marginal lands for these feedstock crop productions, the caution should be taken when China decides to bring large amount of the marginal land into operation. Availability of water resources and environmental implications of expanding feedstock production in new marginal land needs further investigation.

The impacts of China's bioethanol development on its agricultural economy show that while there will be effects, but the effects differ largely among commodities. The prices of the feedstocks will rise substantially, but its impacts on the prices of other agricultural commodities are minor or moderate. Despite the projected increase in the prices of the major feedstocks will significantly increases in the production of these commodities, if China wants to reach its bioethanol production target in 2020, China will still have to import significant amount of its feedstocks from the rest of world. However, the impact of China's "non-grain crops" based bioethanol program on its food security is minimal.

The results from this study have important implications for China's future bioethanol expansion. First, our analysis shows that lack of availability of new land for feedstock production will be one of major constraints in China's biofuel expansion. Second, caution should be taken as there will be large environmental implications of bringing millions of hectares of marginal land into crop production. Potential land suitable for biofuel feedstock crop production should be revisited. Third, there will also be substantial financial implications of promoting a large-scale bioethanol program based on non-grain feedstocks because the feedstock prices will rise significantly with expansion of bioethanol. Fourth, given the availability of land and water resources, China may need to put its more efforts on the second-generation of bioethanol technologies. The use of feedstocks, such as crop residues—along with the potential importance of their alternative uses for livestock feed and sustainable crop production management practices—should also be considered.

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