Energy Economics 86 (2020) 104639

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

How does farmers' current usage of crop straws influence the willingness-to-accept price to sell?

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ARTICLE INFO

Article history:
Received 8 March 2019
Received in revised form 10 December 2019
Accepted 19 December 2019
Available online 30 December 2019

Keywords:
Crop residue
CVM
WTA
China

ABSTRACT

To further develop the second-generation biofuel industry, both government and business sectors need to better comprehend the full costs of buying crop straws from farmers – understanding transportation and baling costs alone is insufficient. Due to the limited market activity of crop straws, this paper uses the contingent valuation method to elicit farmers' willingness-to-accept (WTA) price to sell their crop straws in northeast China. The results from finite mixed models showed that the estimated WTA for maize straw was 9.6 yuan/ton, 43.2 yuan/ton and 83.2 yuan/ton across different farm groups. For rice straw, the WTA for the first farm group was 51 yuan/ton and 204 yuan/ton for the second group. Our results also show that both rice and maize farmers place a higher price on crop straw if it is used in more productive ways, such as for domestic fuel, animal feed or selling; but place a lower price when it is burnt as crop residue in the field.

1. Introduction

Developing the second-generation of biofuels has resulted in a greater demand for crop residue as a raw material. With energy security and air pollution becoming the major impediments to sustainable development worldwide, biofuel is regarded as a potential substitute for oil due to advantages of renewability, as well as being environmentally friendly, mature technology and convenient to use (Agarwal et al., 2012). However, the first generation of biofuels produced from conventional starch-based feed stocks caused public concern, given their potential to generate food insecurity issues for a country with such a large population (Clark et al., 2012). The second generation of biofuels, which make use of agricultural wastes including crop straws, have the potential to reduce concerns around food security, improve air quality and enhance energy security (Lal, 2006). Many countries have promoted the use of biofuel, with worldwide consumption increasing from 26.2 million tons in 2005 to 108.6 million tons in 2016 (EIA, 2018). China began promoting biofuel production and consumption early – at the start of the millennium – after it realized biofuel could fulfil a number of important roles in both economic development and environmental protection. As a result of this change, China produced around 2.46 million tons of ethanol and 0.98 million tons of biodiesel in 2015, making it the third largest producer of ethanol globally (USDA, 2015).

In addition to biofuel, crop residues are used in other emerging industries, such as paper, fodder, and fertiliser manufacturing. The high volume of crop straw production provides China with an opportunity to develop such industries. As a major crop-producing country with an increasing production of grain – 610 million tons of grain was produced in 2018, 51% higher than the level in 2000 (CNBS, 2019) – the quantity of crop straws has increased significantly. Due to the expansion of papermaking applications (Mansouri et al., 2012), China was predicted to use nearly 15 million tons of crop residue in pulp production during 2015 (NDRC, 2011a). In the fodder industry, around 220 million tons of crop residue, equivalent to 32% of the overall total was used in 2010. While, during the same year, about 110 million tons were used as fertiliser (NDRC, 2011b).

Gaining a better understanding of the full costs involved with crop straw production can provide evidence for government and business to make informed decisions around the development of this sector. The high price demanded by farmers, in addition to transportation and baling costs, is often cited as a significant barrier to plant development (Glithero et al., 2013a). Therefore, simply knowing the transportation and baling costs is insufficient; it is necessary to assess the potential value of straw to farmers before commercialization. Specifically, what is the opportunity cost for farmers to sell their crop straws to the market

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https://doi.org/10.1016/j.eneco.2019.104639
0140-9883/

for biofuel and other uses? The value of straw to individual farmers can be revealed by their current utilisation or disposal methods (Glithero et al., 2013a, 2013b). However, given the lack of active markets for crop straws, it is not straightforward to assess the opportunity cost for farmers to sell – and in turn obtain the value to farmers of utilising crop straws for various purposes.

The contingent valuation method (CVM) is commonly used to elicit the value of a private or public good when there is no or very limited market transactions for such a good. However, only a small number of studies have examined how farmers value crop straws, while none of these have included China. To the best of our knowledge, this study is the first to use the CVM to elicit the value of straw to farmers in China. It also seeks to identify the effect of current crop straw management techniques on this value. As highlighted by the literature, the method of crop utilisation may determine farmer valuation (Glithero et al., 2013a, 2013b) resulting in a number of benefits. Firstly, identifying how farmers' straw management influences their value of straw can assist government in targeting specific farmer groups and selecting the most cost-effective incentives to encourage farmers to supply straw on the commercial market. Secondly, it can predict farmers' valuation of straw as straw utilisation changes over time. Finally, it can assist private entrepreneurs to determine the break-even point for investing in new plants that buy straw from willing farmers.

Therefore, the aim of this paper is to investigate the valuation of different crop straws by Chinese farmers. Specifically, we firstly estimate the willingness-to-accept (WTA) prices to sell crop straws and the corresponding supply curves. This is followed identifying the various impacts of crop straw utilisation on WTA. The remainder of the paper is organized as follows: Section 2 reviews the literature on straw valuation; Section 3 presents the data; Section 4 presents the methods including hypothesis development; empirical results and discussions are reported in Section 5; while Section 6 concludes the paper.

2. Literature review on straw valuation

Given the straw market is inactive and incomplete in many countries, the majority of studies have applied a financial approach to evaluate opportunity costs, only considering the agronomic values, along with handling, transport and storage costs. Kludze et al. (2013) discovered the break-even price, representing the minimum price necessary to cover all variable and fixed costs for the farmer, was between \$57/ton and \$87/ton in Ontario, Canada during 2004–08. Other studies found short-term break-even field-edge crop residue prices of \$26–42/ton in Iowa and \$54–73/ton in North Dakota (Archer et al., 2014); while farmers would not participate in stover harvest for biofuels at a price lower than \$44/ton in the US Midwest (Pratt et al., 2014). Another range of studies adopted a market simulation model to derive the biomass supply at a regional level, but assumed the crop residue price under different scenarios. For example, Khanna et al. (2011) estimated the potential biomass supply in the US was 617–923 million tons at a price of \$140/ton, depending on the crop residue collection technology, production costs, yields of perennial energy crops, and land availability. Chen (2016) estimated the economic potential of crop straw supply in China at various exogenously given biomass prices, and identified the areas that were likely to produce crop straws. These estimates demonstrated that China could potentially produce 174–248 million dry tons of crop straws per year when biomass prices are larger than \$100 per ton.

Non-market valuation methods, such as the contingent valuation method (CVM), have the advantage of directly eliciting the price that farmers are willing to accept to sell crop straws given the lack of existing markets. However, only a small number of studies have applied these methods to crop straws – in countries such as the US and Italy. Bergtold et al. (2014) found that farmers were willing to either forfeit or require additional net returns in order to produce biofuel feedstocks, depending on the favourability of the contract negotiated. For example, they were willing to accept a reduction in net return of US\$1.60 per acre for maize stover, if the length of the contract was reduced by one year. However, the study did not present the absolute value of crop straws elicited from farmers. Altman et al. (2015) employed producer surveys in mid Missouri and southern Illinois, and found there was an increase in the willingness to supply between 1.6% and 2.4% per dollar within the price range of \$10–20 per ton of dry straw. Giannoccaro et al. (2017) surveyed 203 cereal growers in the Apulia region of southern Italy and found farmers' WTA price was 15.15 EUR/ha to sell their cereal straw on the feedstock market.

Occasionally straw is traded on the market and its value can be revealed by the market price. For example, farmers in the Indian Trans Gangetic Plains (TGP) collect, store and use wheat straw as feed, and then sell surpluses on the market (Erenstein, 2011). Wheat straw was sold at 1.5 Indian rupees per kg (INR/kg) on average, although this reached a seasonal high of 2.1 INR/kg during winter months. Across the 157 farms surveyed, 75% of wheat straw was used as stall-feed, 18% was sold, and the remaining 7% burnt on field; while only 24% of rice straw was used as stall-feed, 9% was sold, 45% burnt on field, and 22% for other purposes. It is suggested that because of the differences in straw management methods, rice straw in the TGP has a limited intrinsic value compared to wheat straw, which is more widely collected, used or traded. Jat et al. (2014) reported a similar finding in the Eastern Gangetic Plains, whereby the price of wheat straw ranged from 1.1 to 3 INR/kg, while the price of rice straw varied between 0.3 and 1.5 INR/kg, during the time period 2006–13. According to our survey data, only a few farms (<5% of the total sample) in northeast China sold their crop straws during 2013, with the reported price ranging from 150 yuan/ha to 1500 yuan/ha.[1]

3. Data

To study the value of crop straws based on farmers' WTA, this paper employs a dataset from a survey of grain farms conducted in the three provinces of northeast China (i.e. Heilongjiang, Jilin and Liaoning) towards the end of 2013. Fig. 1 displays the geographic location of our sample. The three provinces are major grain production areas, producing 35% of total maize and 16% of total rice outputs across China (CNBS, 2016). As a result, a large amount of crop straws are produced. It is estimated that the collectable amount of crop straws in northeast China are 90 million tons for maize and 40 million tons for rice (Qiu et al., 2014). This region enjoys a warm temperate monsoon climate, with the mean temperature ranging from 18.6 °C to 19.3 °C in the growing season and from −17.5 °C to −7.1 °C in winter over the past 20 years (Zhai et al., 2017). The high latitude (40°N to 50°N) and long, cold, winter (about 220 freezing days) (Zhou et al., 2017) makes it difficult for crop straws to decompose in open fields, which is a significant barrier to the practice of conservation agriculture, such as no tillage and crop residue retention.

A stratified random sampling is used. In the three northeast provinces, two maize and two rice counties were randomly selected from major maize- and rice-producing counties, respectively. In each county, two townships were selected according to the level of land consolidation. Similarly, two villages were selected from each township. In each village, ten farms, including three large farms and seven small farms, were randomly selected from their groups for interviews. In total, the entire dataset consisted of 480 farm households from 48 villages in 12 counties across the three provinces in northeast China. For each household, we randomly selected two plots planted with the main grain crops. For a more detailed description of the dataset, please refer to Huang and Ding (2015). Comparisons between our sample characteristics and the National Agricultural Census (NAC) characteristics in 2006

[1] The exchange rate of Chinese Yuan to US\$ ranged between 6.05 and 6.25 yuan for 1 US \$ in 2013.

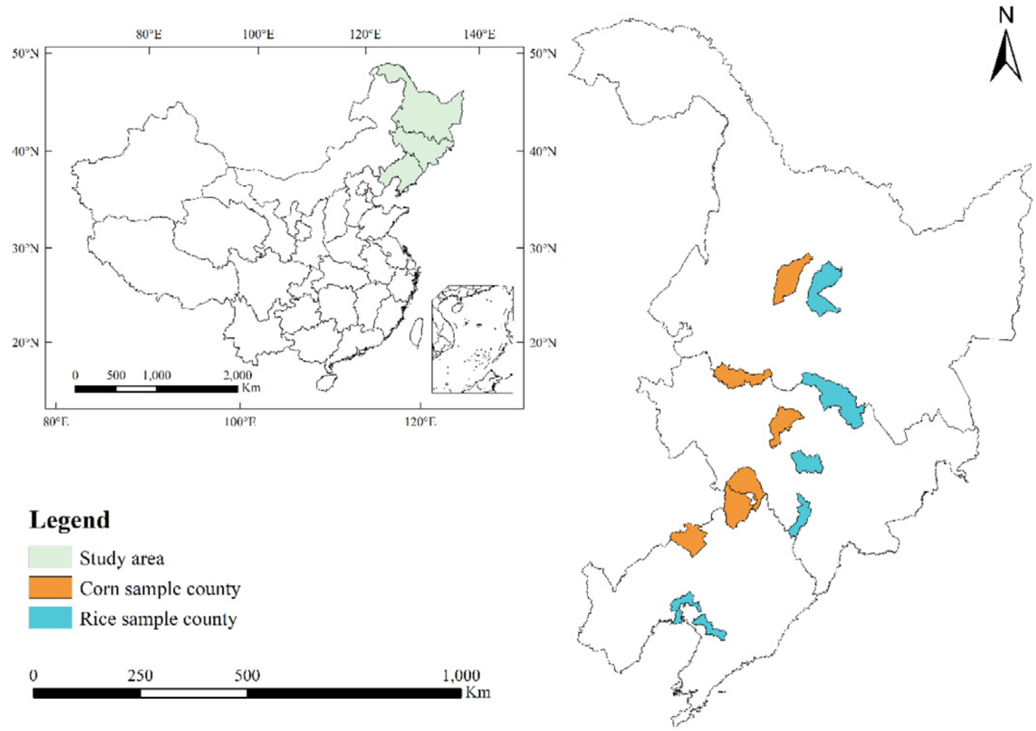

Fig. 1. Study area in northeast China.

for the three northeast provinces suggest that the survey sample is reasonably representative.[2]

In face-to-face interviews, for the straw section of the survey, farmers were asked to answer how they utilised their straw from each of their two plots during 2013. For each utilisation method (i.e. open field burning, field retention, animal feed, domestic fuel, commercial sale and other), a percentage of total stubble volume was provided. The contingent valuation method was then used to elicit how much farmers were willing to pay (WTP) for the straw to be cleared for commercial use, assuming they did not pay for the cost of straw bundling and transportation. If they answered they were not willing to pay at all or they chose to not answer, a subsequent question asked farmers how much they were willing to accept (WTA) to sell the straw for commercial use, again assuming they did not need to get the straw bundled or transported. Farmers understood that the sale was a once-off transaction and were reminded to consider their answers seriously – as if they were genuinely willing to pay the stated price for the straw to be cleared or sell their straw at the stated price. No specific information on the use of straw supplied was elaborated and, as stated in the question, it is referred to 'commercial use in general by a third party'. The open-ended questions were:

"Are you willing to pay for the straw on this plot to be cleared for commercial use, given that you will not pay for the cost of straw bundling and transportation? If so, how much yuan per mu? You can answer 'zero' if you are not willing to pay at all or choose not to answer this question.

[*If no answer or answering zero*] How much yuan per mu are you willing to accept for the dry straw on this plot to be cleared for commercial use, given that you will not pay for the cost of straw bundling and transportation? You can answer 'zero' if you think you do not need to be paid or choose not to answer this question."

Our data shows that the vast majority of farmers did not offer to pay for clearing the field. We therefore used willingness to accept (WTA) as the valid measurement for farmers' valuation of crop straws. The distribution of farmers' WTA or WTP is shown in Table 1. Only 41 (4.4%) of the 922 plots had positive numbers for WTP. Among the 41 plots, eight also had a positive WTA value, suggesting these eight observations were potentially invalid and hence removed from the dataset. For each of the remaining 33 plots, we assumed a zero WTA value given their positive WTP values. For WTA, there were 36 plots with missing information, resulting in 878 plots with legitimate WTA values. Although 179 (20%) of these plots had a WTA of zero, we concluded this represented farmers' true valuation of crop straws, given the majority also had a zero WTP value. Therefore, we treated WTA as a continuous variable not censored at zero.

Table 1
Distribution of number of plots (n = 922) by values of WTP and WTA.

	WTP = missing	WTP = 0	WTP > 0	Total
WTA = missing	0	36	0	36
WTA = 0	0	146	33	179
WTA > 0	0	699	8	707
Total	0	881	41	922

[2] Note that the 2006 NAC (National Bureau of Statistics, 2008) is the closest to our survey year of 2013 as the third NAC in 2016 has not yet published the regional level data. Specifically, for the three northeast provinces, average age for adults over 25 years old was 46 years old; our survey's average age for household head was 50 years old. It is generally expected that household heads are older than the general adult population and therefore our sample appears reasonably representative in terms of household head age. The average household labour was 2.83 from the 2006 NAC while our sample recorded an average of 2.97. The 2006 NAC suggests there were 9% of rural households that had off-farm work in the three northeast provinces while our data suggests in 2013 there were 22% of sample households that had off-farm work. This difference may be due to the fact that off-farm work has become increasingly popular in rural China and seven years after 2006, the percentage of households having off-farm work has increased considerably from 9% to over 20%.The average number of school years for the adult population was 8.0 from 2006 NAC and our sample's average for household head was 7.6 years. Given household heads are generally older than the general adult population and older individuals are less educated in rural China, it is reasonable that the average school year from our sample of household heads is slightly smaller than the 2006 NAC figure.

4. Methods

4.1. Hypothesis development

In rural China, straw has traditionally been used by households in a variety of ways, e.g. domestic fuel, livestock feed, composting and construction, once making it a valuable resource (Yang, 2017). Farmers are only willing to sell straw in a market if the price exceeds the opportunity cost determined by how farmers currently use their straw (Kludze et al., 2013; Altman et al., 2015). Therefore our first two hypotheses are:

Hypothesis 1. Farmers who use straw as domestic fuel or animal feed place a higher value on it; the higher the percentage of straw used as domestic fuel or animal feed, the higher farmers' willingness to accept (WTA) to sell.

Hypothesis 2. Farmers who use straw as an organic fertiliser or land cover to retain soil moisture place a higher value on it; the higher the percentage of straw retained in the field, the higher farmers' willingness to accept (WTA) to sell.

There are some farmers who have already realized the monetary value of straw by selling to a third party for alternative uses, such as paper, bio-fuel, fodder, etc. (Yang, 2017), although these transactions are still scarce. The small number of farmers who have already sold straw on the market could be better informed about the monetary value of straw; and to supply straw to the market the price needs to be above the opportunity cost of alternative uses, such as domestic fuel and animal feed. Therefore, our third hypothesis is:

Hypothesis 3. Farmers who have sold straw place a higher value on it; the higher the percentage of straw sold, the higher farmers' willingness to accept (WTA) to sell.

Over the past few decades, efficient fossil fuels, feed concentrates and fertilisers have been increasingly utilised, resulting in farmers having less need for straw. Commercial utilisation of straw is still relatively uncommon and selling straw on the market is rare. Farmers are increasingly forced to leave stubble in the field and burn it, due to the high labour costs in cleaning up the field and transporting cleared straw (Yang, 2017). Therefore the main economic benefit to farmers of burning straw is the saving in labour and transportation costs from collecting that straw. Assuming farmers do not need to get straw bundled or transported, if there was a market for alternative utilisation of straw, our final hypothesis is:

Hypothesis 4. Farmers who burn straw in open field place a lower value on it; the higher the percentage of straw burnt, the lower farmers' willingness to accept (WTA) to sell in the market.

We believe that the causal relationship is from straw utilisation to farmers WTA price, and not vice versa. Since the commercial market for straw is limited, farmers' utilisation of straw does not depend on how much they can sell the straw on the market. Instead, other factors such as traditional practices, government regulations and incentives may influence how farmers utilise straw. Consequently the intrinsic value of straw is only revealed to farmers through utilisation methods; and farmers' WTA price to sell straw needs, at the least, to exceed this intrinsic value.

4.2. Regression models

We adopt the finite mixture model (FMM) to analyse the influencing factors on farmers' WTA. The FMM is used to model outcomes from a sample that is suspected to be composed of more than one homogenous subsample, especially when we cannot identify which subsample a farmer belongs to. An important feature of FMMs is that they report the coefficients varying across classes, in terms of both signs and magnitudes, to account for latent heterogeneity in regression. The FMM classifies observations, adjusts for clustering, and models unobserved heterogeneity in the data (for more details see McLachlan and Peel, 2000). These features, together with the literature that often reports a greater level of heterogeneity among the farmer population (e.g. Qin et al., 2011; Komarek et al., 2012; Zheng et al., 2013), leads us to adopt FMMs.

Furthermore, our outcome variable also demonstrates a potential to use FMMs. The distribution of WTA appears to be right-skewed, with a large amount of low WTA values for both maize and rice (Fig. 2).[3] Farmers' WTA price varies considerably and may not originate from a single normal distribution. The observed WTA price is presumed to belong to unobserved subgroups named classes, and FMMs are utilised to model farmers' WTA price. In the current study, we are particularly interested in how the signs and magnitudes of coefficients for the crop straw utilisation variables differ among classes.

In an FMM, the observed responses y are presumed to originate from g distinct classes $f_1, f_2, \ldots, f_g$ in proportions $\pi_1, \pi_2, \ldots, \pi_g$. The density of a g-component mixture model can be written as:

$$f(y) = \sum_{i=0}^{g} \pi_i f_i(y|x'\beta_i)$$

where π_i is the probability of an observation belonging to the ith class ($0 \le \pi_i \le 1$), $f_i(\cdot)$ is the conditional probability density function for the observed response in the ith class model, x' is a vector of independent variables and β_i is a vector of parameters for the independent variables. The multinomial logistic distribution is used by an FMM to model the probabilities for the latent classes. The probability for the ith latent class is given by:

$$\pi_i = \frac{\exp(\gamma_i)}{\sum_{j=1}^{g} \exp(\gamma_i)}$$

where γ_i is the linear prediction for the ith latent class. Robust standard errors, clustered at the farm level, are used to account for the possible correlation in WTA from plots that belong to the same farm and the presence of heteroscedasticity.

The key independent variables are farmers' utilisations of crop straws. Farmers reported their utilisations of crop straws as percentages for six methods; i.e. open field burning, domestic fuel, on-plot retention, animal feed, sold to a third party, and others. We could therefore include five variables in the regression model, with the sixth as a baseline. However, only a handful of observations (around 4%) selected 'others' as one of the utilisation methods, and the percentage of crop straws in the 'other' category is considerably small (1% being the highest), which created high correlations among the first five variables, particularly between opening burning and domestic fuel. We therefore excluded the observations reporting 'others' as the crop straw utilisation and used open field burning as the baseline in the regression models.

Among the five utilisation methods for both maize and rice, using crop straws as domestic fuel was by far the most popular. On average, 49% of straw per maize plot was used as domestic fuel, while for rice straw this figure was 58%. Open field burning was the next most common way of crop straw disposal for both maize and rice, accounting for around 25%, with field retention accounting for around 15%. Using crop straws as animal feed or selling it on the market was less common (under 5%), while rice straw was not used as animal feed at all.

[3] There are a few WTA price observations above the highest reported market price (1500 yuan/ha) for crop straws. Since the market price range was based on very few observations, it is likely that the real highest market price is well above 1500 yuan/ha. Given that WTA price only measures the minimum price at which farmers are willing to provide crop straws, it does not suggest that WTA price should be comparable to the market price for each individual farmer. Therefore, we consider the reported WTA price above 1500 yuan/ha up to 6000 yuan/ha still reasonable.

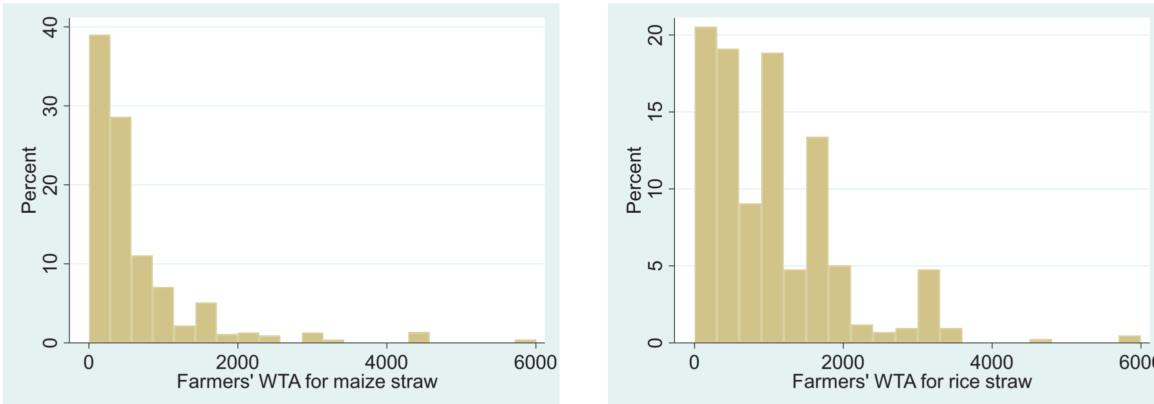

Fig. 2. Distribution of farmers' WTA price (yuan/ha) to sell crop straws.

Besides the straw utilisation variables, we included a range of other variables in the regression models, indicating plot and farm/farmer characteristics and province dummy variables. These variables, suggested by the literature (Christiaensen and Heltberg, 2012; Supaporn et al., 2013; Launio et al., 2014; Shi et al., 2014; Dyer et al., 2015; Zhang, 2017; Giannoccaro et al., 2017) have the potential to influence straw supply and subsequently affect farmers' WTA price. It should be noted that the amount of straw produced on each plot is not collected and therefore is not included in the models. Since maize and rice differ in terms of straw characteristics and plot characteristics, we modelled their WTA price separately. The summary statistics of the dependent and independent variables for maize and rice regression models are shown in Table 2.

Table 2
Summary statistics of variables.

	Maize (n = 419)		Rice (n = 417)	
	Mean	Standard deviation	Mean	Standard deviation
WTA price (yuan/ha)	587.10	833.40	982.95	894.30
Crop straw utilisation (%)				
Open field burning	26.67	42.47	24.31	40.22
Domestic fuel	48.90	46.46	58.41	45.54
On-plot retention	16.41	36.09	12.75	31.53
Animal feed	5.43	19.15	0.00	0.00
Sale	2.59	15.42	4.53	19.07
Plot characteristics				
Size of plot (ha)	0.81	1.15	0.99	1.67
Irrigation condition				
Surface water only (1 = surface water only, 0 = others)	0.00	0.00	0.80	0.40
Groundwater only (1 = groundwater only, 0 = others)	0.19	0.39	0.20	0.40
Neither surface nor ground water (1 = neither, 0 = others)	0.81	0.39	0.00	0.00
Farm and farmer characteristics				
Years of education of household head	7.81	2.13	7.24	2.53
Age of household head	50.08	10.25	51.06	9.23
Number of labour in the household	2.91	1.15	3.06	1.20
Whether the household head has off-farm work in 2013 (1 = yes, 0 = no)	0.22	0.42	0.23	0.42
Province dummies				
Jilin province (1 = Jilin, 0 = others)	0.32	0.47	0.36	0.48
Liaoning province (1 = Liaoning, 0 = others)	0.35	0.48	0.35	0.48
Heilongjiang province (1 = Heilongjiang, 0 = others)	0.33	0.47	0.28	0.45

5. Result and discussion

To provide a meaningful interpretation, it is important to ensure each class includes a reasonable number of samples. Given the sample sizes for maize and rice were 419 and 416 respectively, we restricted the number of classes to the maximum of three. Based on Bayesian information criterion (BIC) diagnoses (Table 3), we selected the 3-class FMM as our final model for maize and the 2-class FMM for rice. For the maize model, the 3-class model has the lowest BIC, and the probabilities for one plot to be in each of the three classes were significantly different. For the rice model, the 2-class and 3-class models did not have significantly different BIC values (4466 vs. 4464). In addition, the probabilities of one plot being in class 2 and class 1 are statistically insignificant in the 3-class model, suggesting that there is no significant difference between the two classes. Therefore, a 2-class FMM was chosen for the rice model. The FMM results further suggest that 57% of the maize sample are belong to class 1, and 29% for class 2 and 14% for class 3, respectively; 87% of rice sample are belong to class 1 and 13% for class 2.

For maize, the estimated WTA prices for the 3-classes were 180 (accounting for 57%), 810 (29%) and 1569 yuan/ha (14%) respectively (Table 4).[4] For rice, the estimated WTA prices were 765 (accounting for 87%) and 3060 yuan/ha (accounting for 13%) respectively for the two classes. <15% of plots were associated with a relatively high value for straw (Class 3 for maize and Class 2 for rice), while the majority were associated with a relatively low value. This finding is consistent with expectations, since no active straw market exists and farmers generally do not realize the potentially high value from alternative straw utilisation given the current utilisation methods. According to the literature (Qiu et al., 2014), 1 ha maize produces 18.75 tons of maize straw, while 1 ha rice produces 15 tons of rice straw. Therefore, on a per ton of straw basis, the estimated WTA prices for maize were 9.6, 43.2 and 83.7 yuan/ton respectively for the three classes, while for rice the prices were 51 and 204 yuan/ton respectively for the two classes.

The next set of results from the FMM reveal which variables influence the WTA to sell crop straws, allowing us to test the hypotheses developed previously. Hypothesis 1 is generally supported by the results, i.e. farmers who use straw as domestic fuel or animal feed place a higher value on it, compared with open field burning. For example, for every one percentage point increase in maize straw being used for domestic fuel rather than burning open field, the WTA price for class 1 will increase by 1.14 yuan/ha; while for class 3, the WTA will increase by 13.70 yuan/ha. Similarly, for every one percentage point increase in

[4] The mean of WTA estimates was obtained through the post-estimation command (estat lcmean) after the finite mixture model (FMM). Specifically, it produces predicted means of the outcome within each latent class. Interested readers may refer to StataCorp (2017, p20) for the detailed formula.

Table 3
BIC of one, two and three classes FMMs.

Crop	Model	BIC
	1 class FMM (OLS equivalent)	4568
Maize	2 class FMM	4247
	3 class FMM	4211
	1 class FMM (OLS equivalent)	4568
Rice	2 class FMM	4466
	3 class FMM[a]	4464

[a] Class 2 membership and class 1 membership are not significantly different.

maize straw being used for animal feed rather than burning open field, the WTA price for class 2 will increase by 8.06 yuan/ha; while the WTA for class 3 will increase by 30.21 yuan/ha. However, for class 1 maize plots (57% of all maize plots), the use of maize straw as animal feed is not significantly associated with farmers' WTA price. For every one percentage point increase in rice straw being used for domestic fuel rather than burning open field, the WTA price for class 1 will increase by 4.53 yuan/ha; the WTA for class 2 will increase by 11.02 yuan/ha. Since rice straw was not used for animal feed by any farmers, its impact on the WTA price cannot be estimated.

Hypothesis 2 is only partially supported, i.e., a significant influence of stubble retention is only found for rice straw. For every one percentage point increase in rice straw being retained on field as an organic fertiliser or land cover to retain soil moisture, rather than burning open field, the WTA price for class 1 will increase by 4.22 yuan/ha; while the WTA price for class 2 will increase by 6.03 yuan/ha. Retaining maize straw on field does not have a significant impact on farmers' WTA price. This result suggests that the value of maize straw is not realized by farmers through field retention, while field retention of rice straw did increase its value to farmers. This may be explained by the difficulties and infeasibility in retaining maize straw. Given the current technology, maize straw in northeast China cannot decay over the cold winter, which affects next year's seedling. From discussions with farmers during our field trip in northeast China, we find that they do not see the benefits in maize retention, while rice retention is technologically mature and more popular among farmers.

Hypothesis 3 is supported by the rice results, but weakly supported by the maize results. For every one percentage point increase in rice straw being sold on the market, the WTA price for class 1 will increase by 8.90 yuan/ha; while for class 2 the WTA price will increase by 18.36 yuan/ha. Every one percentage point increase in maize straw being sold on the market significantly increases the WTA price for class 3 by 20.34 yuan/ha; while for the other 2 classes, selling maize straw on the market is not significantly associated with farmer+s' WTA price. Information completeness plays a role in influencing farmers' WTA and the few farmers who sell straw on the market are generally better informed in terms of its monetary value, enabling these farmers to perform a more accurate evaluation of their straw. As the straw market becomes more developed and a greater number of farmers participate in the market, consequently, farmers' WTA price may increase. However, as market price information becomes more accessible, it will become more convenient for farmers to evaluate whether it is worthwhile selling their straw at the prevailing market price.

Finally, Hypothesis 4 is supported by the results for both maize and rice, i.e. farmers who burn straw place the lowest value on it. Since open burning is used as the base utilisation method and omitted from the models, we compared the effect of other utilisation methods against open burning. Our results show that, for maize straw, open burning is associated with a lower WTA price against the domestic fuel utilisation for class 1; the animal feed utilisation for class 2; and domestic fuel, animal feed and sale on market utilisations for class 3. For rice straw, open burning is associated with a lower WTA price against the other three utilisations (domestic fuel, on field retention and sale on market) with varying magnitudes in both classes. This clearly demonstrates that for many farmers, straw burning has a low opportunity cost, and farmers

Table 4
FMM results for farmers' WTA price (yuan/ha) by crop.

	Maize (obs. = 419)						Rice (obs. = 416)			
	Class 1		Class 2		Class 3		Class 1		Class 2	
	Coef.	Robust standard error	Coef.	Robust standard error	Coef.	Robust standard error	Coef.	Robust standard error	Coef.	Robust standard error
Crop straw utilisation (%)										
Domestic fuel	1.14**	0.50	0.35	1.47	13.70***	3.07	4.53***	0.89	11.02***	2.89
Retention	0.20	0.59	0.06	2.06	−1.01	4.92	4.22***	1.50	6.03*	3.61
Animal feed[a]	−0.16	0.78	8.06**	3.26	30.21***	4.29	–	–	–	–
Sale	1.56	1.69	0.24	3.51	20.34***	4.33	8.90***	1.97	18.36***	4.03
Plot characteristics										
Size of plot (ha)	−12.06	8.07	122.19	97.45	−214.28	135.63	−17.98	13.89	1601.55***	321.78
Surface water only (versus ground water only)[b]	–	–	–	–	–	–	−155.27**	78.55	−1238.86***	258.98
No irrigation (versus ground water only)[c]	−124.30**	58.77	−628.33***	122.98	−1143.65**	578.27	–	–	–	–
Farm and farmer characteristics										
Years of education of household head	1.48	8.03	15.42	31.14	196.73***	65.09	9.38	17.34	74.50	53.46
Age of household head	−1.57	2.27	−7.00**	3.79	59.18***	9.89	6.69	4.77	−11.47	10.37
Number of household labour	−8.22	14.57	−66.45***	21.14	19.26	139.47	−41.30	34.15	−79.96	117.04
Off farm work of household head in 2013 (1 = yes, 0 = no)	−0.12	46.30	244.66**	116.80	−1144.90***	429.07	−93.43	88.19	−283.64	257.13
Province dummies										
Jilin (versus Heilongjiang)[d]	−62.33	47.94	568.03***	105.94	991.50***	333.43	–	–	–	–
Liaoning (versus Heilongjiang)[d]	−6.93	55.39	163.30	128.30	798.32***	280.88	–	–	–	–
Constant	343.22***	167.66	1275.64***	353.03	−3122.89***	779.89	187.58	334.54	1267.33*	669.41
Mean WTA price estimate (yuan/ha)	180		810		1569		765		3060	
Class probability	0.57		0.29		0.14		0.87		0.13	

*, ** and *** represent statistical significance at the 0.10, 0.05 and 0.01 levels, respectively.
[a] Animal feed for rice straw is zero for all the rice plots.
[b] Surface water only is zero for all maize plots.
[c] No irrigation is zero for all rice plots.
[d] Province dummies are not used due to high co-linearity with surface water only variable within each class.

who burn a higher proportion of straw are willing to accept a lower price to sell.

Besides the varying influences of straw utilisation methods, a number of other variables are found to significantly affect farmers' WTA price. These variables appear to have different significance levels among the classes of farmers and between the two crops. The different significance levels among the classes of farmers for the socio-economic variables indicate a degree of heterogeneity regarding the effect of these variables on WTA price, and treating the effect constant among different farmer groups may lead to biased results.

First, irrigation conditions affect farmers' WTA price for both maize and rice straw. For maize, if a plot is not irrigated, the WTA price is significantly lower compared with ground water only irrigated plots. Ground water irrigated plots have higher production costs compared to rain fed plots, as farmers have to pay electricity costs and depreciation costs of pumping equipment. Consequently, farmers using ground water irrigation expect a higher WTA price, as it is more costly to produce the same amount of straw. This finding is consistent with Launio et al. (2014), who discovered farmers in the Philippines were more likely to remove straw from the field (hence a lower WTA price is implied) in the wet season if the land is not irrigated. For rice, if a plot is only surface-water irrigated, the WTA price is significantly lower compared with groundwater-only irrigated plots. In particular, the point estimate of the difference is 155.27 and 1238.86 yuan/ha for classes 1 and 2 respectively. Groundwater irrigation is normally more expensive than surface water irrigation in northeast China. Therefore, a higher WTA price is associated with the plots with groundwater irrigation rather than those with surface water irrigation.

Second, plot size only affects the WTA price for rice straw rather than maize straw. A larger plot size is significantly associated with a higher WTA price for rice for class 2 farmers. Similarly, in Hubei province in China, Zhang (2017) found that a larger land area was associated with a higher likelihood of farmers' straw marketization behaviour.

Third, household characteristics influence the WTA price for maize straw, while unlike maize, household characteristics do not appear to influence the WTA price significantly for rice straw. For class 2 in maize model, having an older household head, a larger amount of household labour, or the household head not working off-farm in 2013, is all associated with a lower WTA price. Similarly, Launio et al. (2014) found higher levels of household labour (measured as number of household members older than 13 years) were associated with a greater willingness to remove straw from the field for other uses instead of burning; while Giannoccaro et al. (2017) found no off-farm employment was associated with lower WTA price. Conversely, for class 3, an older household head or the household head not working off-farm are associated with a higher WTA price. Furthermore, having a better educated household head results in a higher WTA price for maize straw for class 3, echoing the findings of Zhang (2017) – although Launio et al. (2014) found education level was not a significant factor.

Straw supply curves are derived from the maize and rice samples respectively and shown in Fig. 3. The supply curve is drawn by accumulating the available straw weight of each plot (conversion rate of 1 ha maize = 18.75 tons maize straw and 1 ha rice = 15 ton rice straw) at each of the WTA price levels (from lowest to highest) estimated by the FMM parameters, and expressed as a percentage of the total available straw across the whole sample. Given that our sample is representative of the major maize- and rice- producing counties in northeast China, using a percentage measurement for the supply curve makes our estimated supply curve readily applicable in northeast China. The horizontal axis can be easily converted to weight of straw, to derive a supply curve for the aggregate weight of straw to be supplied, as long as the total available straw is known. Our sample indicates that maize straw could be supplied much cheaper than rice: firstly, just over 20% of maize straw could be supplied at zero price, however farmers are not willing to supply any rice straw without compensation; secondly, at a price of 250 yuan/ton, almost 100% of maize straw can be supplied for sale while for rice straw, even at a price of 500 yuan/ton, the supply is still <80%; thirdly, the response of rice straw supply to price is relatively inelastic compared to that of maize straw supply, in the price range up to 150 yuan/ton.

6. Conclusion

This article is the first to estimate the value of crop straws for farmers practicing current utilisation methods in China, using a contingent valuation method. The results from FMM models show that the estimated WTA prices to sell maize straw are 9.6 yuan/ton, 43.2 yuan/ton and 83.7 yuan/ton across different groups of farmers. The WTA price for rice straw estimated from the first farm group is 51 yuan/ton and 204 yuan/ton for the second group. Moreover, supply curves for maize and rice straw are derived.

Our study serves as a starting point for the economic valuation of crop straw in China prior to the straw market becoming more widely available. The results provide valuable information for government and business to assist in determining the feasibility of commencing new biofuel enterprises or other activities utilising crop straws. Furthermore, this study provides guidance on the level of incentives that may be paid to farmers in order to discourage open-field straw burning – which causes a number of negative externalities, such as impacts on human health and traffic hazards.

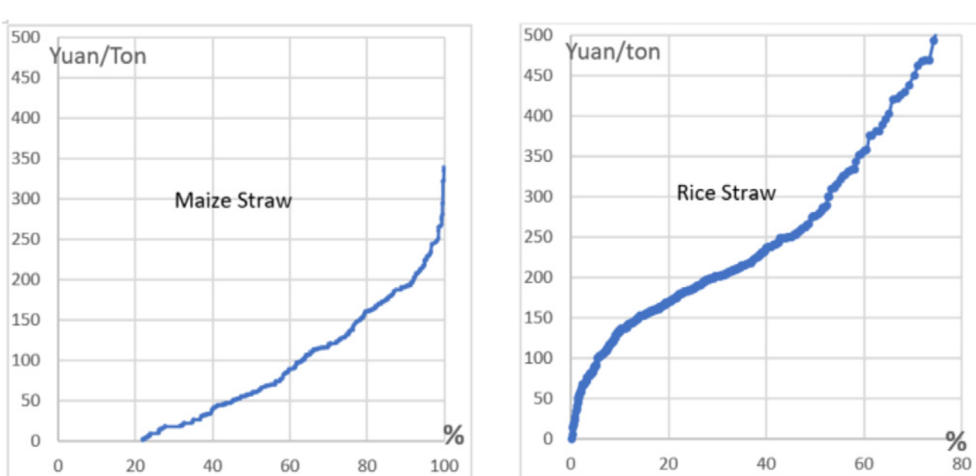

Fig. 3. Estimated maize and rice straw supply curves.

We also examined how farmers' current utilisation affects their WTA prices to sell crop straws. The results show that both rice and maize farmers place a higher value on crop straw if it is used in a more productive way, such as for domestic fuel, animal feed or selling. However, the WTA price only increases with the percentage of stubble retention for rice straw, not maize straw. The possible reason for this is that the technology for maize straw retention is still emerging. Maize farmers are concerned with a potential yield reduction the following year if straw is retained, given it is problematic to decay during the cold winter in northeast China. Burning crop residue in the field implies the least value of straw to farmers; therefore, it is unsurprising to see that the WTA decreases as the percentage of burning crop residue increases. These results not only confirm the hypotheses that farmers' WTA prices are highly correlated with the opportunity cost for the current usage, but can also provide predictions of WTA prices under different utilisation methods. The supply curves developed based on our results can be of assistance to estimate the total amount of crop straws farmers are willing to sell at different prices, and can be adjusted to the levels of different crop straw utilisation methods.

Like all studies using the contingent valuation method, hypothetical bias is pervasive. The current study asked farmers both WTP and WTA for straw disposal, and cross validations of both WTP and WTA revealed a high level of consistency between the answers. Although the elicitation approach in the current study (single open-ended format) was basic, it was nevertheless easy to understand by the interviewees, which reduced their potential cognitive dissonance (Loomis, 2014). We acknowledge that our elicitation may still suffer from hypothetical bias, causing the WTA estimates to be different from respondents' true values. Future research in this field may adopt a more advanced design, such as incentive compatible auction experiments, and compare the elicited WTA values with those obtained from a basic CVM instrument in the Chinese context.

Author contribution

Alec Zuo analyzed the data and wrote up the method and results section. Lingling Hou conducted the survey, cleaned the data and wrote up the data and introduction section. Zeying Huang wrote up the literature review. All authors contribute to revising and polishing the paper.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Grant number 71773003, 71742002, 71303226). The authors are grateful for reviewers' constructive comments that much improved this manuscript.

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