The Economic Causes Of Crop Residue Burning in Western Indo-Gangetic Plains*

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Abstract

Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods, in the Indo-Gangetic plains, has led to substantial emission of trace gases and particles.This paper seeks to uncover the factors that explain on field residue burning of rice residues in Indian Punjab. The results suggest that the use of a Combine Harvester is the single most important determinant of the decision to burn rice residues. The decision to use the combine harvester in turn is determined by the rice variety sown by a farmer. Coarse rice growers are more likely to use a Combine Harvester. Other factors which were considered important like size of livestock and technical ability of the farmer do not seem to have an impact on the decision to burn rice residues. These results have important implication for mitigation policies to reduce residue burning in this region.

1 Introduction

Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods, in the Indo-Gangetic plains, is an important source of atmospheric pollution in this region (Venkataraman et al., 2006). Consequently, regional climate, and consequently crop output (Auffhammer et al., 2006), and the health (Long et al., 1998) of the population are adversely affected. What factors explain on field burning of crop residues in Indian Punjab? In this paper, I examine this question in the context of rice residues; an extremely important issue given that understanding why farmers burn is imperative to prescribing policy reforms. Hence I hope to make a contribution to mitigation policies to reduce residue burning in this region.

The 'rice-wheat cropping system' (RWCS) is the dominant cropping system in South Asia spanning over an estimated 12 million hectares in 1991 and extending over the four countries of Bangladesh, India, Nepal and Pakistan (Hobbs and Morris,

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1996). This system involves that rice and wheat be grown in rotation throughout the year. Rice and wheat may be grown in the same plot in the same year or in different plots in the same year or in the same plot in different years. In India the rice-wheat system was spread over 9.1 million hectares in 1991(Hobbs and Morris, 1996).The states of India with the largest areas under rice-wheat cropping systems are Uttar Pradesh, Punjab, Haryana, Bihar, Madhya Pradesh, and Himachal Pradesh.

The residue to product ratio (RPR) indicates the amount of residue available for each tonne of crop produce. Thus, an RPR of 2 would indicate that 2 tonne of residue is produced for 1 tonne of crop produce. In case rice is cut at about 2 inches above ground, the RPR of rice straw equals 1.75 whereas it falls to 0.452 if only the top portion of the rice stem is cut (Koopmans and Koppejan, 1997). Using these RPR values Koopmans and Koppejan (1997) estimated that about 507,837 thousand tonnes of on field crop residue was generated in India during 1997 of which 43 percent was rice and 23 percent wheat. The estimates from Streets et al. (2003) imply that 16 percent of this crop residue was burnt. The results from Venkataraman et al. (2006) suggest that 116 million metric tonnes of crop residue was burnt in India in 2001, but with a strong regional variation. A majority of the fires occurred in the western Indo-Gangetic plain during the months of May and October corresponding to the two major harvesting seasons for rice and wheat. The authors' conclude that 'the harvesting of cereal wastes and their field burning in major agricultural states such as Punjab, Haryana and Western Uttar Pradesh is the largest potential contributor to these emissions.'

Emissions from the burning of fossil fuels and biomass have led to the creation of atmospheric brown clouds of black carbon and aerosols in various parts of the world (Auffhammer et al., 2006). These clouds reduce surface radiation and rainfall(Auffhammer et al., 2006). Auffhammer et al. (2006) found that joint reductions in brown clouds and greenhouse gases had complementary, positive impact on rice harvests. The authors' estimate that rice yield and the area harvested would have increased by 14.4 percent during 1985-1998 if brown clouds and greenhouse gases had been reduced. Gustafsson et al. (2009) employed radiocarbon analysis (14C) as an atmospheric tracer to measure biomass and fossil-fuel contributions to the South Asian atmospheric brown cloud. They found a much larger contribution of biomass combustion to black carbon emissions (46% for elemental carbon and 68% for soot carbon) than do other tracer techniques. Thus, they stipulated that 'both biomass combustion (such as residential cooking and agricultural burning) and fossil fuel combustion should be targeted to mitigate climate effects and improve air quality'. Emissions of black carbon are the second most contribution to current global warming, after carbon dioxide emissions Ramanathan and Carmichael (2008). The authors' claim that in the Himalayan region heating from black carbon at higher elevations has as large an effect on the meting of snowpacks and glaciers as heating due to greenhouse gases. Furthermore, when black carbon is deposited over snow and sea ice, it darkens the snow thereby significantly enhancing solar absorption by snow and ice leading to a retreat of the Arctic sea ice. It is also well established that large concentration of aerosols lead to the creation of fog that reduces visibility. Low visibility causes multiple accidents and delays in road, railway and air transport.

Long et al. (1998) studied the health consequences from burning of agricultural residue. They surveyed 428 participants with underlying respiratory disorders and exposure to pollution from burning of agricultural residues. The authors' found that people with underlying respiratory disorders were susceptible to the air pollution caused by burning of agricultural residue.Underlying symptoms either became worse or additional air pollution related symptoms were induced. In summary, biomass combustion needs to be regulated to mitigate these health and climate effects. The first step in this direction involves understanding why farmers burn. The objective of this study is to try and provide an answer to this question and the setting is Indian Punjab.

2 Literature Review

There is limited research examining the factors that influence the decision to burn crop residues. Erenstein et al. (2007b) seek to understand the spatial and seasonal diversity in farming practices across the Trans-Gangetic Plains (Punjab and Haryana) particularly in terms of crop livestock interactions. The primary data source for the study in Punjab is a village level survey with self selected groups of informants from the district of Patiala. The authors' find that the practice of in-situ burning as a land preparation measure is present for both the rice and the wheat crops. However, rice residues are burnt on a much larger scale than wheat residues. Only rice residues from Basmati varieties are used as animal feed. Coarse rice residues are not fed to livestock due to the perceived high silica content and fear of reduced milk yields.

They contend that the choice of the harvesting mode (manual or combine) has direct implications for crop residue management. Manual harvesting of cereal crops allows for retrieval of crop by-products as crops are cut at near ground level. Combine harvesters on the other hand make residue recovery difficult as the residue is unevenly spread over the harvested fields. Despite this 85 percent of the surveyed households in the Patiala cluster reported combine use. The authors' attribute the popularity of combine harvesters to potential cost savings, reduced labour management problems and enhanced timeliness. Manual harvesting is widespread for Basmati varieties for reasons such as reduced breakage, more prone to lodging (reducing effectiveness of mechanical harvesting), more limited field size and more intensive residue use.

Gupta et al. (2004) attribute the open field burning of crop residues to combine harvesters that leave a large amount of loose residue on the field. The authors' assert that a major constraint in a rice- wheat cropping system is the available short time between rice harvesting (late October and early November) and sowing of wheat (November). Given this short time, farmers find it difficult to utilise the residue and hence opt for burning.

3 Study Area and Sampling

The state of Punjab, which is the site for this study, is in north-western India. In 2006-2007, Punjab was the fourth largest producer of rice and second largest producer of wheat in India, producing 11 percent of the country's rice output and 19 percent of its wheat output (Ray, 2008). With rice and wheat yields of 3858 Kg per hectare and 4179 Kg per hectare respectively in 2005-06, the state occupied the top position in the country in terms of food grain yield (Ray, 2008). The ratio of net irrigated area to net area sown stood at 0.95 in 2005-06 and is the highest in the country (Ray, 2008).

Punjab is divided into 17 districts. The districts of Amritsar, Ludhiana and Sangrur were purposively selected to undertake the survey. I chose these 3 districts because I wanted to capture geographical variation across Punjab (see Appendix 1).

In the second stage, 10 villages were selected for sampling from each of the districts, using the probability proportional to size technique. This technique ensures that farmers in larger villages have the same probability of getting into the sample as farmers in smaller villages and vice-versa.

The list of villages was obtained from the 2001 Census of India data. Within a village voter lists constituted the sampling frame. A voter list assigns a unique household number to each household in a village and specifies the names of all household members who are at least 18 years of age at the time of the preparation of the list. The decision to use the voter list as a sampling frame was taken after conducting a census of a village. The census revealed that the voter list is not grossly distorted. Consequently it was decided to use the voter list as a sampling frame.

Each village is bound to be populated by people who do not engage in any farming activity. Hence on an average 40 households were randomly selected from each voter list. If the first household amongst the 40 households was a farm household it was included in the survey else it was dropped and the second household was contacted. This procedure was followed until the enumerator was able to complete 10 interviews. However, 32 farm households were purposively surveyed and hence had to be excluded from the analysis.

I define a farm household as a group of individuals related by blood or marriage living on the same premises and sharing a kitchen and practising the rice-wheat cropping system. The respondents to the questionnaire were men who were actively involved in day to day farming activity.

Data were collected at plot level as a farm is not one consolidated unit. The total farm area is distributed across plots and farmers follow different practices on different plots. The size of a farm unit is arrived at by summing farm land owned and farm land leased in and subtracting from this total farm land leased out. The total number of plots for which data were collected are 604.

To sum up, I collected data on 604 plots belonging to 268 farm households from 30 villages across 3 districts of Punjab. I conducted this survey between January and April in 2010.

4 Data and Descriptive Statistics

Farmers foremost decide on the rice variety to be sown and the area to be sown to each variety. Rice is a Kharif[1] crop hence it is sown in the months of June-July.

For 90 percent of the respondents the price and yield of various varieties during the previous growing season were the key factors in arriving at this decision. The Food Corporation of India (FCI) procures rice and wheat from the farmers for which the minimum support price (MSP) is announced by the Government of India. Farmers are free to sell any quantity of grain at this price. The fine grain (Basmati) varieties do not fall under this scheme. The minimum support price was announced on 20^{th} August in 2009 hence farmers had to rely on the prices that had prevailed during the previous season. The Food Corporation of India (FCI) further classifies

[1] There are 2 growing seasons in India i.e. Kharif and Rabi. Kharif crops are usually sown with the beginning of rains in June- July, during the south west monsoon season.

Coarse varieties into grade A and common varieties. The minimum support prices for grade A variety and common variety were fixed at 980 Rs per quintal ($21 per quintal) and 950 Rs per quintal ($20 per quintal) respectively in 2009. The fine-grain varieties are priced within the range of 2000-3500 Rs per quintal ($43-$75) depending on its quality. During 2008-2009 the price of PUSA 1121 Basmati variety was pegged at 2000 Rs per quintal[2]. This prompted farmers to increase the area sown to this variety in the following season.[3] Consequently, in my sample 75 percent of the Basmati area is under the PUSA 1121 variety.

The survey results indicate that 21 percent of the respondents cultivate Basmati varieties and 47 percent of the respondents cultivate Coarse varieties. 32 percent of the respondents grow both type of varieties.

Table 1 shows the district-wise distribution of gross cropped area under fine grain (Basmati) and Coarse varieties for each of the three districts in the sample. In totality Basmati and Coarse varieties are planted on 271 hectares and 869 hectares but there is significant variation across districts. 71 percent of the gross cropped area sown to Basmati falls in Amritsar and 52 percent of the gross cropped area sown to Coarse variety lies in Ludhiana. Hence fine grain varieties are predominantly grown in Amritsar. This is because the agro-climatic conditions of this region are conducive to growing Basmati varieties.[4]

Table 1: Districtwise Distribution of Gross Cropped Area Under Basmati and Non-Basmati Varieties in Punjab, 2010

District	Area Sown to Basmati (Hectares)	Percent of Area Sown to Basmati	Area Sown to Coarse (Hectares)	Percent of Area Sown to Coarse
Amritsar	191	71	87	10
Ludhiana	39	14	450	52
Sangrur	41	15	332	38
Total	**271**	**100**	**869**	**100**

[2]Source:Amritsar Procurement Centre (Mandi)
[3]Source:Businessworld, 2009 and focus group discussions with farmers.
[4]Source:The Tribune, 2005 and conversations with farmers and agricultural scientists.

Table 2a:Variety of Rice-Basmati

Method of Harvesting	No. of Hectares	Percent of Area Sown to Basmati
Family Labour	15	6
Hired Labour	**162**	**60**
Combine Machine	94	35
Total	271	101

Table 2b:Variety of Rice-Coarse

Method of Harvesting	No. of Hectares	Percent of Area Sown to Coarse
Family Labour	0	0
Hired Labour	0	0
Combine Machine	**869**	**100**
Total	869	100

There are two choices open to the farmers regards the mode of harvesting i.e. manual harvesting or harvesting by machine (Combine harvesters). I find that manual harvesting is popular for the Basmati varieties as the price of Basmati rice far exceeds the price of Coarse rice. Moreover, use of combine harvester results in a loss of grain. However, owing to the shortage of labour many farmers resort to mechanical harvesting for Basmati varieties. For similar reasons, farmers do not have any incentive to employ labourers for harvesting Non-Basmati varieties. These findings are in agreement with Erenstein et al. (2007b) and are reported in Table 2a and Table 2b.

Table 3:District-wise Mean Rental Rate of Combine and Contract Labour during Harvest time of Rice crop in Punjab

District	Mean Rental Rate of Combine Rupees per Hectare (US$[a] in Parenthesis)	Mean Rental Rate of Contract Labour Rupees per Hectare (US$ in Parenthesis)	Ratio of Mean Rate Labour to Mean Rental Combine
Amritsar	2304	4993	2
	(49)	(105)	
Ludhiana	162q	6871	4
	(35)	(147)	
Sangrur	1619	6378	4
	(35)	(136)	

[a]The exchange rate used through out the analysis is as on September 7, 2008 i.e. USD 1= INR 46.82

It is also much cheaper and quicker to use combine harvesters than to employ labour. These time savings are dear to the farmers as there is a short time between rice harvesting (mid October-early December and sowing of wheat November-early December). Any delay in planting reduces the productivity of the wheat crop. It is because of these reasons that combine harvesters are popular with farmers. Table 3 displays the mean rental rate of Combines and Contract labour across 3 districts of Punjab. Farmers in Ludhiana save about $112 per hectare by opting for a Combine Harvester.The corresponding figures for Amritsar and Sangrur are $56 and $102.

I find that residue of Basmati Variety is used to a larger degree for feeding livestock. 79 percent of all respondents that fed rice residue to livestock, fed the residue of Basmati variety whereas only 17 percent of such respondents utilised the residue from Coarse variety for feeding purposes. 4 percent of these respondents fed the residue of both varieties to livestock.

Table 4

Variety of Rice - Basmati				
	Mode of harvesting			
	Manual		Combine	
Method of disposal	Percent of the Area Sown to Basmati that is harvested using Labour	No. of Hectares	Percent of the Area Sown to Basmati that is harvested using Combine	No. of Hectares
Fully Burnt	1	2	57	53
Partially Burnt	0	0	16	15
Incorporated	0	0	18	17
Removed	99	175	9	9
Variety of Rice - Coarse				
Fully Burnt	0	0	76	657
Partially Burnt	0	0	16	141
Incorporated	0	0	4	33
Removed	0	0	4	38

Furthermore, the mode of harvesting influences the choice of crop residue disposal. Presently four options are available to the farmers for disposal of residue namely complete burning of residue, partial burning of residue, incorporation of residue and removal of the residue from the field. The Combine harvester leaves two types of residue on the field i.e. loose residue and intact residue. Intact residue is the stalk of the rice plant that is left standing in the field after the combine has cut the top most portion of the plant that carries the grain. Its height varies from 8 to 10 inches. Loose residue is the residue that is scattered by the combine after the harvesting and threshing of the rice crop. This part of the residue is hard to retrieve as it is unevenly distributed over the field. Complete burning involves burning loose and intact residue. Partial burning involves burning loose residue only.

As Table 4 shows, rice residue from 2 hectares was burnt after manual harvesting while residue from 866 hectares was burnt post harvesting by a Combine machine. Residue of Basmati varieties that are hand harvested are sought after as 99 percent of this residue is cleared from the field. On the other hand residue of Coarse varieties that are combine harvested are not considered to be valuable as 92 percent of such residues are burnt.

Table 4 displays the aggregated results.The district-wise estimates reveal that burning of residues is less pronounced in Amritsar (See Appendix 1 Table 1-3). This is not surprising as there is a stringent ban against burning of rice residues in Amritsar.

Monetary savings and enhanced timeliness seem to provide the driver for burning rice residues (See Table 5). Farmers who cultivate potato following rice need to burn rice residues as potato cultivation requires land to be clean. Some farmers also burn because they believe that burning of residues leads to the destruction of weeds that may cause harm to the subsequent crop.

Table 5: Reasons for Burning Rice Residue

Serial No.	Reason	Percent of respondents that burnt rice residue[a]
1	Saves Money	51
2	Machinery that enables ploughing of residue is unavailable	48
3	Saves Time	48
4	Others	11

[a]Percentages to not add up to 100 as respondents could provide multiple answers to this question.

5 Model and Results

Let b=1 denote burning of residue and b=0 otherwise. Likewise c=1 denotes usage of a combine machine and 'c=0' otherwise. Let b^* be an unobserved, or latent variable, determined by

$$b^* = x_b'\beta_b + \epsilon_b \qquad and \quad b = \begin{cases} 1 & \text{if} \quad b^* \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

where x_b' is a vector of farmer specific attributes, (e.g. age, education, farm size etc.), and ϵ_b is a disturbance term having a zero mean. Hence the i^{th} farmer will choose to burn residue on the p^{th} plot if

$$\begin{aligned} Pr[b = 1|x] &= Pr[b^* > 0|x] \\ &= Pr[x_{ib}'\beta_b + \epsilon_{ib} > 0|x] \\ &= \Pr[\epsilon_{ib} > -(x_{ib}'\beta_b)|x] \\ &= 1 - F[-x_{ib}'\beta_b] \end{aligned}$$

where F is the cumulative distribution function of ϵ_{ib} and ϵ_{ib} is independent of $x_{ib}'\beta_b$.

The functional form of F will depend on the assumptions made about ϵ_b. A probit model arises from assuming that ϵ_b is normally distributed with a unit variance.Then F is the standard normal cumulative distribution function Φ. Thus, for a farmer 'i', the probability of burning rice residue and using a combine machine, respectively, is given by:

$$\begin{aligned} Pr[b = 1|x] &= \Phi[x_{ib}'\beta_b] \\ Pr[c = 1|x] &= \Phi[x_{ic}'\beta_c] \end{aligned}$$

The two equations can be estimated consistently by single equation probit methods. But in my model, one of the important covariates in the equation of burning, the mode of harvesting, is likely to be jointly determined with the burning indicator. As the preceding section illustrates, farmers who value the residue of the Basmati variety are more likely to hand harvest and opt for removal of the residue from the field. Thus farmers simultaneously decide on the mode of harvesting and the method of residue disposal. A single equation probit method is inefficient in that it ignores the possibility of correlation between the disturbances ϵ_b and ϵ_c in the underlying latent variable models(Greene, 1998). In this case, the disturbances have a bivariate normal distribution and these equations should be estimated using a bivariate probit model Greene (1998).

Greene (1998) also proves that in a bivariate probit model, if the dependent variables are jointly determined, we can put each on the right side of the other equation (or, in my case, one of them) and can ignore the simultaneity problem. Hence I can treat, the mode of harvesting, like any another explanatory variable in the equation of burning of rice residue.

The bivariate probit model considers two binary outcomes that are potentially related via correlation of errors that appear in the underlying latent variable models.

Specifically, the two outcomes are determined by two unobserved latent variables,

$$
\begin{aligned}
b^{*} &= x_b'\beta_b + c\gamma + \epsilon_b \\
c^{*} &= x_c'\beta_c + \epsilon_c \\
E[\epsilon_b|x_b, x_c] &= E[\epsilon_c|x_b, x_c] = 0 \\
Var[\epsilon_b|x_b, x_c] &= Var[\epsilon_c|x_b, x_c] = 1 \\
Covar[\epsilon_b, \epsilon_c|x_b, x_c] &= \rho
\end{aligned}
$$

We observe the two binary outcomes

$$
b = \begin{cases} 1 & \text{if} \quad b^{*} \geq 0 \\ 0 & \text{otherwise} \end{cases} \qquad and \qquad c = \begin{cases} 1 & \text{if} \quad c^{*} \geq 0 \\ 0 & \text{otherwise} \end{cases}
$$

The model collapses to two separate probit models for b and c if $\rho = 0$ because when ρ is zero, the covariance between ϵ_b and c equals zero. The most suitable technique of estimating a bivariate probit model is full information maximum likelihood.

The variables used in this study to explain the choice of the method of residue disposal include the mode of harvesting, rice variety sown, human capital, innovativeness, scale of operation, ownership of livestock, family size and location.

The mode of harvesting is captured by introducing a dummy variable that equals 1 if the farmer used a combine harvester. Since the usage of a combine harvester makes it difficult to retrieve the resultant residue farmers using combine harvesters are more likely to burn residues (See Table 4). The discussion in the preceding section suggests that a binary variable for the rice variety sown appear in the equation of burning. This binary variable is labelled Coarse and it equals 1 if the variety of rice sown on a plot is Coarse and 0 otherwise. Such a variable is assumed to be exogenous as the decision to sow a particular variety is primarily driven by its price during the previous season. Given the prices and the favourable agro-climatic conditions, farmers in Amritsar find it profitable to cultivate Basmati varieties. The availability of human capital is indicated by years of education of the farmer. Innovativeness and technical ability are proxied by the viewer-ship of a programme related to farming, contact with extension services and whether the farmer reads agricultural magazines. Small scale farmers may be more inclined to remove the residue from the fields for feeding livestock. The raw data in fact suggests that small scale farmers are more likely to remove residue from fields. This effect of the scale of operation is captured by farm size. The number of livestock owned per hectare of farm area indicates the demand for fodder relative to its supply. The higher is the number of livestock owned per hectare of farm area the greater is the demand for rice residues as rice residues are used as livestock feed. The discussion in the preceding section, however, suggests that this effect may vary by the rice variety sown. Hence, I introduce a variable that interacts the number of livestock with the rice variety sown by a farmer on a plot. Family size is proxied by the number of family members equal to or above 15 years of age in the household per hectare of farm area sown to rice. Since there was a ban on burning crop residues in the district of Amritsar, a dummy variable indicating the location of a farmer is included as a variable in the equation of burning. The descriptive statistics of the variables included in the analyisis are given in Table 7.

The dependent variables in the equation of mode of harvesting are Coarse, Farm Size, Number of livestock owned per hectare of farm area, Family labour available to the household per hectare of farm area sown to rice, Rental rate of a combine harvester in village, Rental rate of contract labour in village and Amritsar. The discussion in the preceding section indicates that the rice variety sown has implications for the mode of harvesting (manual or combine). Small scale farmers may be more inclined to use their own labour or employ labour for harvesting purposes for Basmati vareties. Farmers who own livestock are more likely to harvest the crop manually but I allow for this effect to vary with the variety of rice sown. Location is captured by retaining the dummy variable Amritsar as an explanatory variable in this equation.

5.1 Discussion Of Results

The estimated marginal effects of the variables in the two equations are given in Table 8. The model has been estimated by bivariate probit methods using maximum likelihood as the estimation criterion. All standard errors have been corrected for clustering at the farmer level. I use Murphy's score test of normality (Murphy, 2007)

Table 7 : Description of the variables used in the analysis

Variables	Description	Unit of Measurement	Continuous Variables		Binary Variables
			Mean	S.D.	
Burnt	Indexes the method of residue disposal on a plot. 1= residue is burnt ,0 otherwise	Percent of Plots			1=64 0=36
Combine	Whether or not farmer used a Combine to harvest rice on a plot. 1= Combine machine is used ,0=otherwise	Percent of Plots			1=74 0=26
Coarse	Type of variety of rice sown by the farmer on a plot. 1=Coarse,0=Basmati	Percent of Plots			1=64 0=36
Farm Size	Size of a farm unit	Hectares	5.03	5.51	
Number of livestock per hectare of farm area		Number	2.46	1.96	
Watch	Whether or not farmer watches a programme on farming. 1=Watches,0=Does not watch	Percent of Farmers			1=56 0=44
Contact with Extension	Whether or not an extension agent visited the farmer in the year preceding the survey 1=Yes,0=No	Percent of Farmers			1=24 0=76
Reads Magazines	Does the farmer read agricultural magazines. 1=Yes,0=No	Percent of Farmers			1=20 0=80
Age of the farmer		Number	51.73	14.21	
Education of the farmer		Number	8.16	4.1	
Number of persons equal to or above 15 years of age in the household per hectare of farm area sown to rice		Number	2.71	2.91	
Rental rate of Combine Harvester in Village		Rupees per Hectare	765 ($16.34)	161.97	
Rental rate of Contract Labour in Village		Rupees per Hectare	2381.67 ($50.84)	591.39	
Amritsar	Dummy Variable that equals 1 if a plot is located in Amritsar,0 otherwise	Percent of Plots			1=33 0=67

Table 8 : Marginal effects of the variables on the joint probability of using a combine harvester and burning the residue[a]
(Dependent Variables are Burnt[b] and Combine[c])

Independent variables	Marginal effect	Reference[d] Values
Combine	.7746*** (9.46)	1
Coarse	.6940*** (8.07)	1
Number of livestock	-.0196 (-0.50)	2.13
Number of Livestock*Coarse	-.0716** (-2.16)	1.23
Farm Size	.0017 (0.19)	6.66
Number of persons equal to or above 15 years of age in the household	.0093 (0.49)	2.03
Watch	-.1166*** (-1.84)	0
Contact with Extension	.0155 (0.25)	0
Reads Magazines	-.1720** (-1.96)	0
Age of farmer	.0010 (0.49)	52.12
Education of farmer	.0043 (0.56)	8.45
Amritsar	-.2042*** (-2.64)	1
Rental rate of Combine Harvester in Village	-.00002 (-0.78)	764.98
Rental rate of Contract Labour in Village	-0.00002 (-1.38)	2380.38
ρ	-0.60 (-1.76)	
N	604	

[a]Figures in Parenthesis are t-ratios
[b]Burnt=1 if the farmer burnt the residue on a plot and 0 otherwise
[c]Combine=1 if the farmer used a combine harvester on a plot and 0 otherwise
[d]Reference values for continuous variables are plot level means
***Significant at the 1% level
**Significant at the 5% level
*Significant at the 10% level

to test the normality assumption in the bivariate model[5]. The p value is 0.5 hence the null hypothesis of normality is not rejected.

The estimated parameter of rho (Table 8) shows that the null hypothesis that the covariance parameter $\rho = 0$ is not rejected at the 5% level, indicating the validity of estimating the two equations separately. This is not surprising. The correlation coefficient measures the correlation between the outcomes after the influence of the explanatory variables is accounted for. Thus, the value, 0.60 measures the effect after the influence of using a combine harvester is already accounted for. However, as discussed later on, the single most important determinant of whether the residue on a plot will be burnt is indeed whether a combine harvester is being used on the plot. Hence I estimate each equation using single equation probit methods.

5.2 Determinants of Mode of Harvesting

I again employ Murphy's score test of normality to test the normality assumption in the univariate model and the null hypothesis of normality is not rejected at the 1% level. The model predicted 91 % of the plots on which a combine harvester was being used correctly, and 91 % of the plots on which manual labour was being used correctly, with an overall correct prediction rate of 91 %.

The only factor affecting the choice of mode of residue disposal is the variety of rice sown by a farmer (Table 9). This is not surprising given the statistics in Table 2a and Table 2b. In particular, on plots that are planted with Coarse varieties, farmers are 81 % more likely to use combine harvesters holding other variables constant at their reference values. The predicted probability of using a combine harvester on a plot is 0.99 for plots that are sown with Coarse varieties and are situated in Amritsar fixing the values of other variables at their means. In contrast, on plots that are planted with Basmati varieties and with other identical features, the probability of using a combine harvester is 0.2. Clearly, the rice variety sown by a farmer has huge implications for the choice of the mode of harvesting.

5.3 Determinants of Method of Residue Disposal

Results of the method of residue disposal model indicate that the model successfully predicted 97 % of all plots on which the rice residue was burnt, and 75 % of all plots on which the residue was not burnt, with an overall correct prediction rate of 89 %.

[5]The null hypothesis is that the errors are from a bivariate normal distribution and the alternative hypothesis is that the errors follow a truncated or type AA Gram Charlier Series. The test statistic is distributed as chi-squared with nine degrees of freedom under the null hypothesis

Using, Murphy's score test, I again fail to reject the null hypothesis of normality of the disturbance terms at the 5 % level.

Table 9 : Marginal effects of the variables on choice of harvesting in Punjab 2010[a]
(Dependent Variable is Combine[b]

Independent variables	Marginal effect	Reference[c] Values
Coarse[d]	.8059*** (13.31)	1
Number of Livestock	-.0067 (-1.23)	2.13
Number of Livestock*Coarse	.0035 (1.10)	1.26
Farm Size	-0.0006 (-0.97)	6.67
Number of persons equal to or above 15 years of age in the household	-.0002 (-0.14)	2.03
Rental rate of Contract Labour in village	-.0000 (-1.21)	2380.38
Rental rate of Combine Harvester in Village	-.0000 (-0.89)	764.98
Amritsar[e]	-.0108 (-1.20)	1
N	604	

[a]Figures in Parenthesis are t-ratios
[b]Combine=1 if the farmer used a Combine harvester on a plot and 0 otherwise
[c]Reference values for continuous variables are plot level means
[d]Coarse is a dummy for the variety of rice sown
***Significant at the 1% level
[e]Amritsar is a dummy for the location of farmer

The marginal effects of the variables in the equation of method of residue disposal are shown in Table 10. By far, the most substantial effect, at the margin, on the probability that the residue will be burnt on a plot is exerted by the usage of a combine harvester. In particular, combine users are 74 % more likely to burn rice residues on a plot holding other variables constant at their reference points. Another factor influencing the decision to burn residues is farm location. Plots situated in Amrtisar[6] are 24 % less likely to get burnt than plots situated in Ludhiana and

[6]The data suggest that some farmers may not have truthfully revealed their method of residue disposal. Hence as a robustness check, I estimated these models assuming that these farmers had burnt the residue. The results did not change on

Sangrur at the specified values of the other variables.

Table 10 : Marginal effects of the variables on choice of residue disposal in Punjab 2010[a]
(Dependent Variable is Burnt[b]

Independent variables	Marginal effect	Reference Values[c]
Combine	.7432***	1
	(8.93)	
Coarse	.1759	1
	(1.50)	
Number of Livestock	-.0452	2.13
	(-1.05)	
Number of Livestock*Coarse	-.0546	1.26
	(-1.44)	
Farm Size	.0026	6.66
	(0.26)	
Number of Persons equal to or above 15 years of age in the household	.0097	2.03
	(0.43)	
Watch	-.1215*	0
	(-1.80)	
Contact with Extension	.0010	0
	(0.14)	
Reads Magazines	-.1815**	0
	(-1.98)	
Age of Farmer	.0013	52.12
	(0.53)	
Education of Farmer	.0045	8.45
	(0.54)	
Amritsar	-.2309***	1
	(-2.89)	
N	604	

[a]Figures in Parenthesis are t-ratios
[b]Burnt =1 if the farmer burnt the residue on a plot and 0 otherwise
[c]Reference values for continuous variables are plot level means
***Significant at the 1% level
*Significant at the 10% level
**Significant at the 5% level

Farmers that read agricultural magazines are significantly less likely to burn rice residues. Ownership of livestock, the size of the farm and availability of human capital do not appear to have significantly influenced the decision to burn rice residues.

account of this assumption.

The predicted probability of burning rice residue on a plot is 0.75 for plots on which Coarse varieties are cultivated and harvested using a combine harvester and that are situated in Amritsar and that are operated by farmers who may not be technical able holding all the other variables at their means. A farmer is assumed to be technically able if he watches the programme on farming, reads agricultural magazines and has a contact with extension services. This probability drops to 0.44 for plots that are operated by farmers that may be technically able but with other identical features. The corresponding probabilities for plots sown with Basmati varieties are reported in Table 11.

Table11

Combine	Predicted Probability of Burning		
	Technically able	Not Technically able	Difference
1	0.26	0.57	0.31
0	0.00	0.00	0.00

As a robustness check, I estimated this equation using a linear probability model with village fixed effects. The results are reported in Table 4 of Appendix 2. Usage of a combine harvester continues to be the most important factor in influencing the decision to burn residues. Farm location also continues to exert an influence on the decision to burn residues. The rice variety sown by a farmer, however, begins to play a role in determining the choice of the method of residue disposal. Farmers that cultivate coarse varieties on a plot and that do not own any livestock are 20 % more likely to burn residues than farmers that cultivate Basmati varieties. This effect decreases with an increase in the number of livestock owned per hectare of farm area. This is because rice residues are used as animal feed. For plots on which coarse varieties are grown the probability of burning decreases by 7 % with a unit increase in livestock owned per hectare of farm area.

6 Conclusion

I find that the single most important determinant of the decision to burn rice residues is usage of a combine harvester. Other variables remaining constant at their reference values, farmers who use a combine harvester are 74 % more likely to burn rice residues than farmers who do not use a combine harvester. This effect is less pronounced in Amritsar. Farmers in Amritsar are about 23 % less likely to burn rice residues than farmers in the other two districts.Thus, the ban imposed on burning rice residues in Amritsar had an impact on the decision to burn rice residues. The decision to use a combine harvester is in turn driven by the rice variety sown by a farmer. Coarse rice growers are 81 % more likely to use a combine harvester than Basmati growers. The number of livestock per hectare of farm area, farm size and variables that measure availability of human capital do not seem to have an impact on the probability of burning rice residue.

Unfortunately the variable that matters the most to the decision to burn crop residues i.e. the usage of a combine harvester, is not amenable to policy intervention. Combines are entrenched in the agricultural system of the states of Punjab and Haryana(Erenstein et al., 2007a). The advantages combine harvesters offer in terms of savings of money and time and reduced supervision of labour have made them immensely popular with the farmers. Presently combine harvesters are being mainly used to harvest Coarse varieties in Punjab but as the discussion in section 4 shows farmers who face labour scarcity resort to mechanical harvesting of Basmati varieties. Thus, in the advent of increased labour scarcity, use of combine harvesters is likely to spread.

A modification to the combine harvester can be made whereby the residue is separately collected. This raises questions about the utilisation of residue. Balers have been introduced in the district of Amritsar and the baled residue is being used to generate electricity in a sugar mill in this district[7]. However, baling of residue may not be a viable mitigation strategy as the supply of baled residue may outweigh its demand. There is no data available on the quantities of residue demanded by the various industries in Punjab and the quantities supplied to substantiate this claim. The alternative that seems viable to me is encouraging development of machines that allow farmers to plant into loose residue. In fact one such machine called 'Happy Seeder' has been developed by research engineers from Australia and India involved in an ACIAR (Australian Centre for International Agricultural Research) Project. 'The HS is a tractor-powered machine that cuts and lifts the rice straw, sows into the bare soil, and deposits the straw over the sown area as a mulch'(Singh et al., 2006). Wheat can be sown immediately after rice harvest precluding the need for burning. Thus, an important research question is whether Happy Seeder is a viable alternative to open field burning of rice residues. This question will be addressed in a subsequent study.

[7]Source:Field Survey

References

Auffhammer, M., Ramanathan, V. and Vincent, J. (2006). Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India, *Proceedings of the National Academy of Sciences* **103**(52): 19668.

Businessworld (2009). Website. `http://www.businessworld.in/bw/2009_10_03_Returns_From_PUSA_1121_Basmati_Variety_My_Dip.html?storyInSinglePage=true`.

Chiburis, R. (2010). Score tests of normality in bivariate probit models:Comment.

Erenstein, O., Thorpe, W., Singh, J. and Varma, A. (2007a). *Crop-livestock interactions and livelihoods in the Indo-Gangetic Plains, India: A regional synthesis*, Cimmyt African Livelihoods Program.

Erenstein, O., Thorpe, W., Singh, J. and Varma, A. (2007b). *Crop-livestock interactions and livelihoods in the trans-Gangetic Plains, India*, ILRI (aka ILCA and ILRAD).

Greene, W. (1998). Gender economics courses in liberal arts colleges: Further results, *The Journal of Economic Education* **29**(4): 291–300.

Gupta, P., Sahai, S., Singh, N., Dixit, C., Singh, D., Sharma, C., Tiwari, M., Gupta, R. and Garg, S. (2004). Residue burning in rice-wheat cropping system: causes and implications, *Current science* **87**(12): 1713–1717.

Gustafsson, O., Krusa, M., Zencak, Z., Sheesley, R., Granat, L., Engstrom, E., Praveen, P., Rao, P., Leck, C. and Rodhe, H. (2009). Brown Clouds over South Asia: Biomass or Fossil Fuel Combustion?, *Science* **323**(5913): 495.

Hobbs, P. and Morris, M. (1996). Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post-Green Revolution era, *NRG paper* **96**(01).

Koopmans, A. and Koppejan, J. (1997). Agricultural and Forest Residues-Generation, Utilization and Availability, *Paper presented at the Regional Consultation on Modern Applications of Biomass Energy* **6**: 10.

Long, W., Tate, R., Neuman, M., Manfreda, J., Becker, A. and Anthonisen, N. (1998). Respiratory symptoms in a susceptible population due to burning of agricultural residue, *Chest* **113**(2): 351.

Murphy, A. (2007). Score tests of normality in bivariate probit models, *Economics Letters* **95**(3): 374–379.

Ramanathan, V. and Carmichael, G. (2008). Global and regional climate changes due to black carbon, *Nature Geoscience* **1**(4): 221–227.

Ray, R. (2008). Agricultural Statistics at a Glance, *Ministry of Agriculture* .

Singh, R., Dhaliwal, H. and Tejpal-Singh, H. (2006). A financial assessment of the Happy Seeder for rice–wheat systems in Punjab, India, *Permanent beds and rice-residue management for rice–wheat systems in the Indo-Gangetic Plain* **7**: 182.

Streets, D., Yarber, K., Woo, J. and Carmichael, G. (2003). Biomass burning in Asia: Annual and seasonal estimates and atmospheric emissions, *Global Biogeochem. Cycles* **17**(4): 1099.

The Tribune, Amritsar Plus (2005). Newspaper.

Venkataraman, C., Habib, G., Kadamba, D., Shrivastava, M., Leon, J., Crouzille, B., Boucher, O. and Streets, D. (2006). Emissions from open biomass burning in India: Integrating the inventory approach with high-resolution Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data, *Global Biogeochemical Cycles* **20**(2): GB2013.

7 Appendix 1

District Map of Punjab

Source: `http://www.villagespunjab.com/cms/images/maps/thumbs/punjab_458x400.gif`

8 Appendix 2

Table 1: District-wise estimates of Table 4

District-Amritsar		
Variety of Rice - Basmati		
	Mode of harvesting	
	Manual	Combine
Method of disposal	Percent of the Area Sown to Basmati that is harvested using Labour in Amritsar (No. of Hectares) (in Parenthesis)	Percent of the Area Sown to Basmati that is harvested using Combine in Amritsar (No. of Hectares) (in Parenthesis)
Fully Burnt	0 (0)	47.45 (29.14)
Partially Burnt	0 (0)	17.13 (10.52)
Incorporated	0 (0)	24.71 (15.18)
Removed	100 (129.90)	10.71 (6.58)
Variety of Rice - Coarse		
Fully Burnt	0 (0)	32.33 (28.13)
Partially Burnt	0 (0)	31.86 (27.72)
Incorporated	0 (0)	28.02 (24.38)
Removed	0.4 (0)	7.79 (6.78)

Table 2: District-wise estimates of Table 4

District-Ludhiana		
Variety of Rice - Basmati		
	Mode of harvesting	
	Manual	Combine
Method of disposal	Percent of the Area Sown to Basmati that is harvested using Labour in Ludhiana (No. of Hectares) (in Parenthesis)	Percent of the Area Sown to Basmati that is harvested using Combine in Ludhiana (No. of Hectares) (in Parenthesis)
Fully Burnt	0 (0)	33.83 (2.63)
Partially Burnt	0 (0)	41.03 (3.24)
Incorporated	0 (0)	0 (0)
Removed	100 (30.55)	25.64 (2.02)
Variety of Rice - Coarse		
Fully Burnt	0 (0)	72.59 (326.68)
Partially Burnt	0 (0)	20.10 (90.47)
Incorporated	0 (0)	1.80 (8.09)
Removed	0.16 (100)	5.51 (24.81)

Table 3: District-wise estimates of Table 4

District-Sangrur		
Variety of Rice - Basmati		
	Mode of harvesting	
	Manual	Combine
Method of disposal	Percent of the Area Sown to Basmati that is harvested using Labour in Sangrur (No. of Hectares) (in Parenthesis)	Percent of the Area Sown to Basmati that is harvested using Combine in Sangrur (No. of Hectares) (in Parenthesis)
Fully Burnt	11.32 (1.82)	86.89 (21.45)
Partially Burnt	0 (0)	6.56 (1.62)
Incorporated	0 (0)	6.56 (1.62)
Removed	88.68 (14.27)	0 (0)
Variety of Rice - Coarse		
Fully Burnt	0 (0)	91.09 (302.60)
Partially Burnt	0 (0)	6.90 (22.91
Incorporated	0 (0)	0 (0)
Removed	0 (0)	2.02 (6.68)

Table 4 : Ordinary least squares estimates of the variables on choice of residue disposal in Punjab 2010[a]
(Dependent Variable is Burnt[b]

Independent variables[c]	Coefficient effect
Combine	.6409***
	(10.17)
Coarse	.2015***
	(3.83)
Number of Livestock	-.0043
	(-0.35)
Number of Livestock*Coarse	-.0654***
	(-4.33)
Farm Size	.0046*
	(1.69)
Number of Persons equal to or above 15 years of age in the household	.0042
	(0.46)
Watch	-.0153
	(-0.54)
Contact with Extension	-.0134
	(-0.44)
Reads Magazines	-.0642*
	(-1.74)
Age of Farmer	.0011
	(0.87)
Education of Farmer	.0011
	(0.28)
Amritsar	-.3551***
	(-2.23)
N	604

[a]Figures in Parenthesis are t-ratios, Standard errors are robust to heteroskedasticity and within-farmer correlation
[b]Burnt =1 if the farmer burnt the residue on a plot and 0 otherwise
[c]Estimates of Village fixed effects are not reported
***Significant at the 1% level
*Significant at the 10% level