Chapter 3
Valuation of the Health Effects

Abstract This chapter measures the value of health effects of air pollution for the Indian rural Punjab, where air pollution problem occurs from crop residue burning. Consumer choice model is used to get the monetary estimates of reduced air pollution level to the safe level. The chapter uses data of 625 individuals collected from a household level survey conducted in three villages in Indian Punjab for 150 households. To obtain the monetary values, Tobit and Poisson models are used to estimate mitigation expenditure and workdays lost equations, respectively. Total annual welfare loss in terms of health damages due to air pollution caused by the burning of rice straw in rural Punjab amounts to Rs 76 millions. If one also accounts for expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility and additional fertilizer, pesticides and irrigation, the losses would be much higher.

Keywords Air pollution · Residue burning · Mitigation expenditure · Workdays lost · Rural Punjab

3.1 Introduction

Epidemiological studies show that the contamination of air quality increases adverse health impacts (Ostro et al. 1995). Air pollution contributes to the respiratory diseases like eye irritation, bronchitis, emphysema, asthma etc., which not only increases individuals' diseases mitigation expense but also affect their productivity at work. Most of the studies valuing health impacts of air pollution remain confined to urban areas as air pollution is considered mainly the problem of urban areas in developing countries. Though health consequences from burning of agricultural residue are not fully understood, relative short exposure may be more of a nuisance rather than a real health hazard, many of the components of agricultural smoke cause health problem under certain conditions (Long et al. 1998).

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This chapter attempts to estimate the value of health effects of air pollution for the rural Punjab, where air pollution problems happen due to crop residue burning.

The rice and wheat system (RWS) is one of the widely practiced cropping systems in India. About 90–95 % of the rice area is used under intensive rice wheat system in Punjab. Widespread adoption of green revolution technologies and high yielding variety of seeds increased both, crop as well as crop residue. In the last few decades intensive mechanization of agriculture has been occurring and combine harvesting is one such input, particularly in the RWS. Note that in the RWS a short period of time is available between rice harvesting and wheat plantation and any delay in planting adversely affects the wheat crop. This coupled with combine harvesting compels the farmers to burn the residue to get rid of it. It is estimated that 22,289 Gg of paddy straw surplus is produced in India each year out of which 13,915 Gg is estimated to be burnt in the field. The two states namely Punjab and Haryana alone contribute 48 % of the total and are subject to open field burning (Gadde et al. 2009). Burning of straw emits emission of trace gases like CO_2, CH_4, CO, N_2O, NO_X, SO_2 and large amount of particulates which cause adverse impacts on human health. It is estimated that India annually emits 144,719 Mg of total particulate matter from open field burning of paddy straw (Gadde et al. 2009).

There are many studies in developed countries that estimate the value of adverse health effects of air pollution (Gerking and Stanley 1986; Dockery et al. 1993; Schwartz 1993; Pope et al. 1995 etc.). Similar evidences are available from India and other developing countries (e.g., Cropper et al. 1997; Kumar and Rao 2001; Murty et al. 2003; Gupta 2008; Chesnut et al. 1997; Alberini and Krupnick 2000). These studies used either household health production model or damage function or cost of illness approaches to estimate the monetary value of health damage caused due to ambient air pollution. Note that these studies are restricted to measure the monetary value of reducing urban air pollution to the safe level since air pollution has been considered mainly the problem of urban areas.

Cropper et al. (1997) using dose-response model find that a 100-μg/m^3 increase in total suspended particulate matter (TSPM) leads to 2.3 % increase in trauma deaths in Delhi. Kumar and Rao (2001) estimated the household health production function using data of working individuals of the residential complex of Panipat Thermal Power Station in Haryana, India and find that individual willingness to pay varies between Rs. 12 and 53 per month for improving the air quality to WHO standards. Using a similar model, Murty et al. (2003) observed that a representative household gains about Rs. 2,086 and 950 per annum due to reduced morbidity from reduction of air pollution to the safe level in Delhi and Kolkata, respectively. Similarly, Gupta (2008) estimates aggregate benefits of the magnitude of Rs. 225 million per year reducing air pollution to the safe level for the city of Kanpur, India. It is however, to be noted that most of these studies remained confined to only Indian urban areas. In the present study, we use a similar consumer choice model to get the monetary estimates of reduced air pollution level to the safe level for the rural Punjab.

We use data of 625 individuals collected from a household level survey conducted in three villages, namely Dhanouri, Ajnoda Kalan and Simro of Patiala district of Punjab for 150 households. To get the monetary values we estimate two equations: one with mitigation expenditure and the other with workdays lost as dependent variables. Tobit and Poisson models are found to be suitable for estimating mitigation expenditure and workdays lost equations, respectively. We find that total annual welfare loss in terms of health damages due to air pollution caused by the burning of paddy straw in rural Punjab amounts to Rs. 76 millions.

The chapter is organized as follows: Sect. 3.2 presents the ambient air quality levels in the study villages during the period when harvesting of rice takes place. Section 3.3 gives details of the design of the household survey and analyzes the households' behavior. Section 3.4 presents some details of the agricultural output and productivity among the selected households and some health indicators. Section 3.5 describes the theoretical model and estimation strategy of mitigation expenditure and workdays lost function. The results are discussed in Sect. 3.6 while last Sect. 3.7 concludes the chapter.

3.2 Ambient Air Quality Level in Study Area

In Punjab, it is common practice to openly burn agricultural residues in fields after harvesting crops by mechanical harvests. Central and State Pollution Control Boards have been monitoring the ambient air quality for certain Indian cities for the last two decades. Monitoring of ambient air quality in rural areas is very sporadic and purpose specific. Given the severity of the problem, the Punjab Pollution Control Board (PPCB) conducted air pollution monitoring in three villages of Patiala districts, namely Dhanouri, Simro and Ajnoda Kalan during November 1–3, 2006. Patiala is one of the agriculturally leading districts of Punjab which is rich in crops like rice and wheat. When monitoring was done in these designated villages, it was ensured that some burning of paddy straw was happening in the fields of these villages. Monitoring stations for the sites were planned keeping in view the metrological conditions and environmental settings in terms of habited and non-habited areas and following parameters were monitored: metrological parameters (temperature, humidity, wind-speed and wind direction), particulate matters ($PM_{2.5}$, PM_{10}, TSPM), gaseous pollutants (SO_2, NO_X, NH_3, CO, Ozone, THC, TC and BTX) and heavy metals.[1]

Descriptive statistics of some of the important pollutants and metrological parameters is given in Table 3.1. The table shows that gaseous pollutants such as SO_2 and NO_X were within the safe limits put under National Ambient Air Quality Standards (NAAQS) and particulate matters either were measured in terms of SPM,

[1] For details, please see the report prepared by Envirotech Instruments Pvt Ltd (2006) on 'Air Pollution Discharged from the Burning of Crop Residue in Agriculture Fields of Punjab' for Punjab State Pollution Control Board, www.envirotechindia.com.

Table 3.1 Descriptive statistics of emissions and metrological data

	PM_{10} (µg/m^3)	SO_2 (µg/m^3)	NO_X (µg/m^3)	Relative humidity (min) (%)	Wind speed (km/h)	Temperature (maximum) (°C)	Temperature difference (maximum minus minimum) (°C)
Mean	306.66	14.20	56.08	46.13	1.78	29.35	16.87
Standard deviation	16.60	2.96	12.32	0.97	0.40	0.60	1.05
Maximum	325.5	17.4	69	47.4	2.35	30.2	18.2
Minimum	284.75	10.25	39.25	45.1	1.425	28.8	15.6

Source PPCB (2007)

PM_{10} or $PM_{2.5}$ and they cross the limits set by the NAAQS.[2] In the study area all the particulates followed same pattern in whatever terms they are measured. The hourly peak values ranged between 300 and 350 and 24 h average concentration ranged between 200 and 300 µg/m^3. The ratio between peak and average was found to be about 1.2, indicating almost uniform concentration over the monitoring period. The contribution of the burning to PM_{10} concentration appeared to be around 100–200 µg/m^3. In all the three monitoring sites, the difference in humidity and temperature levels was negligible and the wind speed was found to be in the range of 0–3.6 km/h. Low wind speed coupled with low wind direction fluctuation implies that the impact of polluting activities remain confined to its close vicinity.

3.3 Household Survey Design and Data

To measure the economic cost of pollution, we needed data on other socio-economic-health indicators in addition to pollutant exited by paddy waste burning in the environment. The health indicators during and after the period of burning, measures adopted by people in the periphery to cope with the situation and other socio, agriculture, income and expenditure parameters were not collected by the PPCB survey. In order to further work on the economic cost, we resurveyed the same villages where PPCB conducted its exercise of measuring air pollutant before and after the burning. This exercise assumes that the findings of the PPCB exercise are still valid and no significant change has occurred neither in the incidences of burning nor in the pollutant emitted into the air by the exercise of burning in those areas.

[2] CPCB has defined the NAAQS implying the safe level of pollutants for residential, rural and other areas as follows: SO_2 60 and 80, NO_X 60 and 80 and PM_{10} 60 and 100 µg/m^3 as annual and 24 h averages, respectively.

Table 3.2 Total sown area and area under rice and wheat in the selected villages in the year 2001

Village	Total sown area (acres)	Area under rice (acres)	Area under wheat (acres)
Ajnouda Kalan	897	365	367
Dhanouri	343	156	130
Simbro	755	342	344

Source Official website, district Patiala

Looking at some of the household and agricultural characteristics, the Nabha Tehsil under Patiala District has a total population of 2,51,326 with 75.33 % of it confined in the rural sector and 24.67 % in the urban sector. Out of operated area 26,395 acres of land is under wheat and 28,359 acres of land is under rice crop in the Nabha Tehsil (Table 3.2). Data on the health status and socio-economic variables of households for this exercise were collected through a household survey conducted for this study for the above mentioned three villages in the month of May 2009 and is based on the recall memory. Selection of households in the respective villages was based on stratified random sampling.

The selection of villages was purposive as has been documented above. After selecting the villages, a list of all households including those who were cultivators, agricultural labourers and those who were working in the other formal or informal sectors like regular government or private services, self-business and pension holders was worked out. Stratification was done for the cultivating households in terms of marginal farmers (≤2.5 acres); small farmers (2.51–5.0 acres), medium farmers (5.01–10.0 acres) and large farmers (above 10.0 acres). The farmers were selected on the basis of stratified random sampling method. From each village, approximately 10 farmers were selected for each category.[3] Thus, total 40 farmers were selected from each village and 120 farmers were selected from all the three villages. In addition to cultivating households, a total number of 10 landless labourers were selected from every village. Thus total 30 numbers of agricultural labourers were selected from all the three villages. Therefore, the aggregate sample consists of a total number of 150 households surveyed for this exercise. The division of selected households from different categories is presented in Table 3.4.

The questionnaire used for the household survey had twelve sections seeking detailed information on various aspects of inputs-outputs used by the farmers for agricultural practices, disposal of crop residues and socio-economic characteristics. Section 1 and 2 of the questionnaire provide information on individual household members' profile in terms of their age, education sex, occupation, marital status etc. Section 3 deals with the information on end use of straw and health effects of the burning. It gives information on the current health status of individuals,

[3] This is purposive selection and may bias the results, but no other alternative to get the required information. Anyhow, this being the first systematic study, at least provides some estimates of the direction on impacts on human health.

symptoms of illnesses linked to air pollution exposure, averting and mitigation activities followed by all the members in a household during the designated months when the paddy straw burning was happening. Sub-sections also provide information on whether a particular individual is suffering from any chronic diseases. There was question also on the general awareness of households about the illnesses that occur due to air pollution. Sections 4–7 seek information regarding agriculture productivity, input usage, stubble management etc. Section 8 and 9 provide information on medical expenditure and workdays lost during the designated period of paddy straw burning. The former section provides information on the expenditure on formal medication such as fee paid to a doctor, expenses on the allopathic medicines, cost of hospitalization etc. while the later section provides information on expenditure incurred on informal medicines that Indian household generally take without consulting any medical professional. Last two sections provide information on individual habits and households assets. Information on the habits includes whether an individual is habitual to smoking, alcohol drinking or/and taking any other toxicants and affect health in general.

3.4 The Survey Results

3.4.1 The Household and Farming Characteristics

The phenomenon of adverse gender ratio whereby male members exceed female members in Punjab is also reflected in our selected sample. Out of the total number of households surveyed in our sample, the ratio of male to female was approximately 55–45 % in all the three villages selected (Table 3.3). Population in working age out of total population of all the surveyed households was 70 %. About 28 % of the surveyed household members in the three villages were illiterate or educated up to primary level only. The highest (64 %) households were educated up to secondary level while only 7 % had higher education above secondary level. 67 % household members were self-employed in farming while 14 % were wage earners and 11 % were involved in formal or informal salaried work.

The average size of holdings was around 7 acres among the selected villages out of which 5.4 acres were irrigated (Table 3.4). On an average, leased-in area was more than leased-out area among the selected households, except in Ajnauda Kalan where leased-out area exceeded leased-in area. The cropping intensity was around two crops in a year among all the selected households. On an average, household assets valued at Rs. 3.5 lakhs that included ownership of tractor, submersible pump set, milch and non milching animals and animal house (Table 3.5). Economics of farming is worked out in Table 3.6.

In addition to rice and wheat grown during *kharif* and *rabi* seasons, some area was also devoted to green fodder crops like *jowar* and *bajra* during the *kharif* season and *barseem* during the *rabi* season. There were some miniscule examples of one or two farmers growing mustard (oilseed), moong (pulse crop), sugarcane and maize.

Table 3.3 Household characteristics (%)

Village name	Family size (No.)	Male in the family	HHs in working age (16–60)	Illiterate	Up to secondary	Above secondary	Self employed in farming	Self employed in non farming	Salaried and pensioners	Wage earners
Dhanouri	5.56	54.68	71.22	26.98	66.55	6.47	67.39	9.78	2.17	20.65
Ajnauda Kalan	5.54	55.23	67.87	29.24	62.82	7.94	67.01	11.34	11.34	10.31
Simro	5.92	53.38	70.95	28.38	63.85	7.77	67.92	1.89	17.92	12.26
Total	5.67	54.41	70.04	28.20	64.39	7.40	67.46	7.46	10.85	14.24

Table 3.4 Farm holding characteristics

Village name	Average operated area (acres)	Leased-in area (acres)	Leased-out area (acres)	Irrigated area (acres)	Cropping intensity	Approximately No. hh in the village	No of selected farmers			
							Marginal	Small	Medium	Large
Dhanori	6.07	4.13	2.00	4.74	1.99	117	10	11	13	6
Ajnauda Kalan	8.43	4.45	5.50	6.12	2.00	380	10	10	10	10
Simro	6.86	3.31	0.00	5.17	2.15	152	10	10	15	5
Total	7.12	4.00	3.40	5.36	2.05	649	30	31	38	21

Table 3.5 Value of assets holding among the farmers (Rs. per household)

	Dhanori	Ajnauda Kalan	Simro	Aggregate
Tractor/trolley	111,700	82,700	122,960	105,787
All other mechanical implements	41,162	46,448	88,658	58,756
Happy seeder	2,000	0	70	690
Thresher	40	1,844	2,858	1,581
Irrigation pump sets submersible	59,500	89,900	40,700	63,367
Irrigation pump set non-submersible	9,660	200	200	3,353
Other mechanized assets	800	3,200	120	1,373
Animal house	27,700	42,300	48,650	39,550
Milching animals	57,400	63,380	56,880	59,220
Non milch animals	14,230	15,320	18,000	15,850
Any other	200	2,060	0	753
Total	324,392	347,352	379,096	350,280

The input-output table is worked out for the major crops of rice, wheat and green fodder. Among these three crops, returns were highest in wheat, followed by rice and green fodder while the latter was mostly produced for domestic animals and the crop was not sold in the market. Irrigation, labour, machine cost and plant protection were the major items of cost of production in rice and wheat while seed was the second significant item in the case of green fodder. The net returns per acre were around 14 thousand for rice and 16.5 thousand for wheat. However, while calculating cost of production, we have not included the rental value of own land, interest paid on fixed capital and depreciation value of implements and therefore value of net returns is exaggerated.

3.4.2 Management of Stubble Among the Selected Farmers

Table 3.7 presents the details of total amount of stubble (by-product) generated on the field, its various uses and various alternatives adopted by the farmers to dispose of the stubble for the two main crops of paddy and wheat. On an average, total amount of stubble generated for paddy and wheat per acre was around 23 and 19 quintals, respectively. Out of this in the case of paddy, more than 85 % was burnt in the open field and less than 10 % was incorporated using rotavator while rest of 8 % was used for other purposes. In the case of wheat, 77 % of the total amount was used as fodder for animals while 9 % was incorporated and around 11 % was burnt. The reason for burning high amount of paddy stubble in the open field was non availability of any machine which can be used to collect the crop remains after the combine harvest.[4] Rotavator was used by around 10 % of the

[4] High wage rate in the state could be another important reason for use of machines and burning of straw.

Table 3.6 Input-output table (Rs. per acre)

Village name	Seed	Manure fertilizer and pesticides	Irrigation	Labour cost including family labour	Cost of machinery	Rent for leasing-in	Other cost	Total cost	Value of total output (+byproduct)	Net returns
Rice										
Dhanori	303	1,527	2,138	1,908	1,924	0	63	7,863	22,191	14,327
Ajnauda Kalan	276	1,493	2,138	2,065	2,133	385	56	8,547	22,454	13,907
Simro	237	1,183	2,064	2,386	1,896	0	185	7,951	21,706	13,755
Total	272	1,401	2,113	2,120	1,984	128	102	8,120	22,117	13,997
Wheat										
Dhanori	853	1,364	953	2,235	1,993	0	138	7,534	24,427	16,893
Ajnauda Kalan	912	1,528	955	2,509	2,031	38	65	8,037	24,924	16,887
Simro	876	1,098	953	2,078	1,821	0	184	7,009	23,001	15,992
Total	880	1,330	953	2,274	1,948	13	129	7,527	24,117	16,590
Green fodder										
Dhanori	1,091	215	400	1,538	449	0	0	3,692	6,982	3,289
Ajnauda Kalan	1,098	269	364	1,436	409	0	4	3,580	8,038	4,458
Simro	1,040	200	395	1,156	743	0	0	3,534	7,072	3,538
Total	1,076	228	386	1,377	534	0	1	3,602	7,364	3,762

Note Total cost does not include, rental value of own land, depreciation of capital and implements and interest on fixed capital

Table 3.7 The amount of stubble generated on the field and its alternate uses

Variable name		Dhanori	Ajnauda Kalan	Simro	Aggregate
Paddy					
Qty of total residue generated (quintals per acre)		22.61	23.50	21.54	22.55
Percentage of residue	Burnt out of the total	87.54	89.47	78.80	85.48
	Incorporated using HS	0.00	0.00	0.00	0.00
	Incorporated using rotavator	5.82	5.26	15.31	8.59
	Sold in the market	0.00	0.00	2.51	0.78
	Used as fodder	0.00	0.00	0.00	0.00
	Used in bio-thermal plant	1.75	2.24	2.51	2.16
	Used in pulp industry	0.00	0.56	0.00	0.20
	Used for other purposes	4.89	2.46	0.88	2.79
Wheat					
Qty of total residue generated (quintals per acre)		19.33	18.98	17.73	18.68
Percentage of residue	Burnt out of the total	10.87	8.17	13.12	10.66
	Incorporated using HS	0.00	0.00	0.00	0.00
	Incorporated using rotavator	10.09	10.80	6.35	9.15
	Sold in the market	1.94	3.29	3.53	2.90
	Used as fodder	76.33	76.42	77.01	76.57
	Used in bio-thermal plant	0.00	0.00	0.00	0.00
	Used in pulp industry	0.00	0.00	0.00	0.00
	Used for other purposes	0.78	01.32	0.00	0.71

households to incorporate rice remains after combine harvest but it could be used only after partly or fully burning the field. On the other hand, in the case of wheat, 90 % of households used reaper driven by tractor after combine harvest to collect the wheat remains that were used as fodder for animals. Among the selected households, less than 7 % in wheat and 2 % in paddy harvested manually to collect the stubble from the field. More than 80 % households in wheat used reaper to collect wheat residue to use it as fodder. In the case of paddy, around 8 % households indicated using machine (rotavator) to remove crop remains from the field while around 90 % households fully burnt the field to remove the crop residue (Table 3.8).

Providing a reasoning why the majority of the households were burning rice residue, around 41 % households indicated that there was shortage of time period between harvesting of paddy crop and sowing of wheat crop. A majority, 48 % indicated that burning was more economical and only around 8 % opined that they were indulging in burning because there was shortage of labour force for manual removal of the residue (Table 3.9). Shortage of time in wheat sowing after harvest of paddy is further confirmed from the data shown in Table 3.10. Among the

Table 3.8 Residue removal practices in the field (% of households)

Methods of residue removal		Manually	By machine	By burning
Dhanori	Rice	2.35	4.71	92.94
	Wheat	5.62	91.01	3.37
Ajnauda Kalan	Rice	0.00	7.14	92.86
	Wheat	5.81	82.56	11.63
Simro	Rice	3.75	13.75	82.50
	Wheat	9.41	69.41	21.18
Total	Rice	2.01	8.43	89.56
	Wheat	6.92	81.15	11.92

Table 3.9 Motivation for burning of crop residue (% of households)

Motivation to burn residue	Shortage of time between harvesting and next crop	Shortage of labour for manual removal	No economical use of crop residue	Burning is more economical
Dhanori	37.80	7.32	0.00	54.88
Ajnauda Kalan	38.75	10.00	5.00	46.25
Simro	48.53	5.88	1.47	44.12
Total	41.30	7.83	2.17	48.70

Table 3.10 Average no of days available for the next crop when crop residue is removed by different practices

Village/crop		Average no of days available for next crop when residue is			
		Burnt in the case of paddy/use of reaper in the case of wheat	Incorporated in soil using happy seeders	Incorporated in soils using rotavator/zero drill	Removed from the field by other means
Ajnauda Kalan	Rice	46	–	44	44
	Wheat	13	–	18	21
Dhanori	Rice	45	–	49	48
	Wheat	13	–	10	–
Simro	Rice	60	–	–	48
	Wheat	13	–	14	16
Total	Rice	48	–	46	47
	Wheat	13	–	15	18

households who burnt the field the average time of sowing interval was 13 days while households who incorporated stubble using rotavator/zero drill, the average interval was 15 days. The average interval went up to 18 days among those households who used manual or other methods of stubble removal. In the case of wheat, however, there was sufficient time of 46–48 days for removal of stubble before the transplantation of paddy putting no additional compulsion on the farmers to burn the field for removal of crop residue. According to 82 % of the selected farmers, the easiest and quickest way of paddy stubble removal was burning while 14 % indicated incorporation using rotavator (Table 3.11). Not only the majority of farmers were of the opinion that burning was the quickest way of stubble removal but they were also convinced that this method of stubble management was ensuing them the maximum crop yield (Table 3.12).

A few farmers who incorporated the stubble of paddy, they used either rotavator or zero drill machines. The happy seeder machine (new invention for incorporating rice stubble) was not yet adopted by any selected farmers (Table 3.13). However, although farmers were convinced that burning was not harming the level of crop yield but they pointed out that burning of field added extra cost to the production because of top soil getting affected by the burning. Some of these farmers observed changes in colour of the top soil on the surface of the land after burning. Farmers indicated that in comparison to incorporation, burning required, on an average, 20–50 kg of extra chemical fertilizer that added Rs. 250–300 per acre extra cost of production (Table 3.14). The farmers who burnt the field (fully or partly) to clear the wheat stubble used 169 kg of urea in the next crop of paddy while those who incorporated or adopted other means used 145 and 148 kg of urea, respectively. Similarly, those farmers who burnt paddy field, used added amount of Di-Amonia Phosphate (DAP) to recapture the nutritive lost in the fire in comparison to those who incorporated or removed stubble manually (Table 3.16). Higher expenses are not only in terms of higher fertilizer but also in terms of higher irrigation requirement by those who burn their field to clear the stubble as indicated by Table 3.15. In paddy the total cost of irrigation was Rs. 2,220 for those who burn their filed in comparison to Rs. 2,000 for the farmers who incorporated the wheat stubble. In the case of wheat, per acre irrigation cost was Rs. 941 for those who burned the field

Table 3.11 The easiest and quickest way to get rid of the crop stubble (% of households)

Crop stubble removal method	Burning	Incorporation using happy seeder technology	Incorporation using other methods	Manual way of harvesting and collection	Removal from the field by other means
Dhanori	89.89	0.00	8.99	1.12	0.00
Ajnauda Kalan	79.55	0.00	14.77	3.41	2.27
Simro	78.82	0.00	17.65	3.53	0.00
Total	82.82	0.00	13.74	2.67	0.76

Table 3.12 Households' perception about which method of crop stubble management gives them the maximum crop yield (% of households)

	Burning	Happy seeder technology	Zero drill/rotavator	Traditional way
Dhanori	83.15	0.00	15.73	1.12
Ajnauda Kalan	71.59	0.00	28.41	0.00
Simro	74.12	0.00	23.53	2.35
Total	76.34	0.00	22.52	1.15

Table 3.13 If crop subtle incorporated in the soil, method used for incorporation (% of households)

Incorporation method	Happy seeder	Zero till drill	Rotavator	Manually
Dhanori	0.00	2.78	88.89	8.33
Ajnauda Kalan	0.00	7.16	92.86	0.00
Simro	0.00	4.00	92.00	4.00
Total	0.00	4.49	91.01	4.49

Table 3.14 Additional fertilize use when crop stubble burning

	Higher amount of fertilizer required for next crop when crop subtle of previous crop burnt			Difference seen on surface of top of soil when residue burnt (% of households)
	Percentage HH	Extra amount of Fertilizer (kg per acre)	Extra amount of Fertilizer (value Rs. per acre)	
Dhanori	14.29	46.67	233.33	14.29
Ajnauda Kalan	10.00	23.00	247.50	17.50
Simro	23.08	53.89	305.56	12.82
Total	15.70	45.11	270.53	14.88

but slightly less, Rs. 907 for those who removed stubble by other means. However, in wheat the cost of irrigation was higher for those who incorporated probably because of additional irrigation requirement for stubble fixation.

3.4.3 The Effect of Crop Stubble Burning on Human Health

As mentioned in the beginning of the chapter, air pollution leads to respiratory diseases like eye irritation, bronchitis, asthma etc., increasing individuals' disease mitigation expenses and also affecting ones' working capacity. In addition, open burning in the field affects life of animals, birds and other insects below and above the earth. Burning at times also causes poor visibility and increases the incidents of road accidents. Our household survey shows that paddy stubble burning among our selected villages leads to air pollution and several other problems. There was no conclusive evidence of smoke caused by stubble burning affecting the health or productivity of the milk producing animals (Table 3.17). On the other hand, a significant numbers of households indicated that smoke caused loss to the vegetation in the field and it also led to accidents taking place on the road during the peak of stubble burning that happens in the months of October and November every year. To our question whether households were aware of harmful effects of residue burning, more than 90 % selected households indicated yes but almost none of them was taking any preventive measures to escape from smoke disease before the beginning of the harvest season.

Table 3.15 The effect of end use of straw on the amount of irrigation used per acre

Village name	End use of previous crop residue	Electric tube well—owned and hired			Diesel tube well		Total charges (Rs.)
		Submersible (No. of hours)	Non submersible (No. of hours)	Charges (Rs.)	No. of hours	Charges (Rs.)	
Paddy							
Dhanori	Residue burnt	15	–	1,000	10	1,500	2,500
	Incorporated	–	–	–	–	–	–
	Other uses	17	20	727	10	1,423	2,150
Ajnauda Kalan	Residue burnt	15	–	600	10	1,500	2,100
	Incorporated	15	–	500	10	1,500	2,000
	Other uses	17	–	781	9	1,367	2,148
Simro	Residue burnt	10	–	833	9	1,350	2,183
	Incorporated	–	–	–	–	–	–
	Other uses	14	–	653	9	1,341	1,994
Total	Residue burnt	12	–	820	9	1,400	2,220
	Incorporated	15	–	500	10	1,500	2,000
	Other uses	16	20	722	9	1,378	2,100

(continued)

Table 3.15 (continued)

Village name	End use of previous crop residue	Electric tube well—owned and hired			Diesel tube well		Total charges (Rs.)
		Submersible (No. of hours)	Non submersible (No. of hours)	Charges (Rs.)	No. of hours	Charges (Rs.)	
Wheat							
Dhanori	Residue burnt	7	10	348	4	563	911
	Incorporated	8	0	500	4	600	1,100
	Other uses	–	–	–	5	700	700
Ajnauda Kalan	Residue burnt	8	–	374	4	611	985
	Incorporated	–	–	–	5	675	675
	Other uses	–	–	–	4	600	600
Simro	Residue burnt	7	–	364	4	561	925
	Incorporated	6	–	313	4	650	963
	Other uses	6	–	200	6	825	1,025
Total	Residue burnt	7	10	362	4	579	941
	Incorporated	7	–	375	4	644	1,019
	Other uses	6	–	200	5	707	907

Table 3.16 The effect of end use of straw on the amount of fertilizer used per acre

Village name	End use of previous crop residue	Manure (Rs.)	Chemical fertilizer (NPK)			
			Urea (kg)	DAP (kg)	MOP (kg)	Value [a]total (Rs.)
Paddy						
Dhanori	Residue burnt	167	167	–	–	1,333
	Incorporated	–	–	–	–	–
	Other uses	150	144	–	–	1,321
Ajnauda Kalan	Residue burnt	350	150	–	–	1,475
	Incorporated	–	145	–	–	1,350
	Other uses	117	139	–	–	1,276
Simro	Residue burnt	100	183	1	–	1,183
	Incorporated	–	–	–	–	
	Other uses	27	161	–	–	1,293
Total	Residue burnt	188	169	–	–	1,313
	Incorporated	–	145	–	–	1,350
	Other uses	98	148	–	–	1,297
Wheat						
Dhanori	Residue burnt	185	131	106	–	1,813
	Incorporated	–	150	100	–	1,690
	Other uses	120	130	100	–	1,760
Ajnauda Kalan	Residue burnt	103	143	94	–	1,759
	Incorporated	250	125	100	–	1,815
	Other uses	–	138	100	–	1,728
Simro	Residue burnt	16	150	91	–	1,629
	Incorporated	100	158	84	–	1,697
	Other uses	–	125	75	–	1,400
Total	Residue burnt	103	141	97	–	1,736
	Incorporated	122	150	89	–	1,722
	Other uses	55	132	95	–	1,683

[a] Total value also includes the expenditure incurred on other chemicals like zink etc., used by the farmers

Irritation in eyes and congestion in the chest were the two major problems faced by the majority of the household members (Table 3.18, Fig. 3.1). Respiratory allergy, asthma and bronchial problems were the other smoke related diseases which affected household members in the selected villages. Almost 50 % of the selected households indicated that their health related problems get aggravated during or shortly after harvest when crop stubble burning is in full swing during the months of October, November and December. In the peak season, affected families had to consult doctor or use some home medicine to get relief from irritation/itching in eyes, breathing problem and similar other smoke related problems. On an average, the affected members suffered at least half a month from such problems and had to spend Rs. 300–500 per household on medicine

Table 3.17 Percentage of household experiencing any problem due to smoke caused by crop stubble burning (mainly rice)

Village/nature of problem	Awareness of harmful effect of residue burning	Family taken preventive measure to escape from smoke disease	Smoke affected productivity of other working members (attendant)	Experienced decline in productivity of milk producing animal	Milk producing animal suffering from sickness	Loss of vegetation due to smoke	Having observed accident happening due to smoke
Dhanori	87.50	2.04	0.00	6.00	0	60.00	8.00
Ajnauda Kalan	92.50	0.00	4.17	0.00	0	59.18	24.00
Simro	95.83	0.00	0.00	2.04	4.08	87.76	89.80
Total	92.19	0.71	1.37	2.68	1.35	68.92	40.27

Table 3.18 Percentage of HH members suffering from the disease due to stubble burning

Problem	Dhanori	Ajnauda Kalan	Simro	Aggregate
Bronchial problems (inflammation of lungs due to infection or other causes)	1.56	2.04	0.00	1.14
Irritation in eyes (eyes feel as being burnt)	75.00	73.47	93.65	81.25
Coughing (congestion in the chest)	34.38	20.41	44.44	34.09
Experience nose/throat irritation due to smoke	4.32	0.00	0.68	1.65
Asthma (shortness of breath, congestion in the chest)	3.13	4.08	23.81	10.80
Emphysema (lung disease due to exposure to smoke, toxic chemicals etc.)	0.00	0.00	0.00	0.00
Respiratory allergies (hay fever caused due to over reaction of the immune system to a stimulus like dust, smoke, air pollutants etc.)	7.81	12.24	15.87	11.93
Other lung and heart disease	0.00	0.00	0.00	0.00
Any other problem	3.13	8.16	1.59	3.98
Health problem gets aggravated during stubble burning	52.00	52.00	42.55	48.98

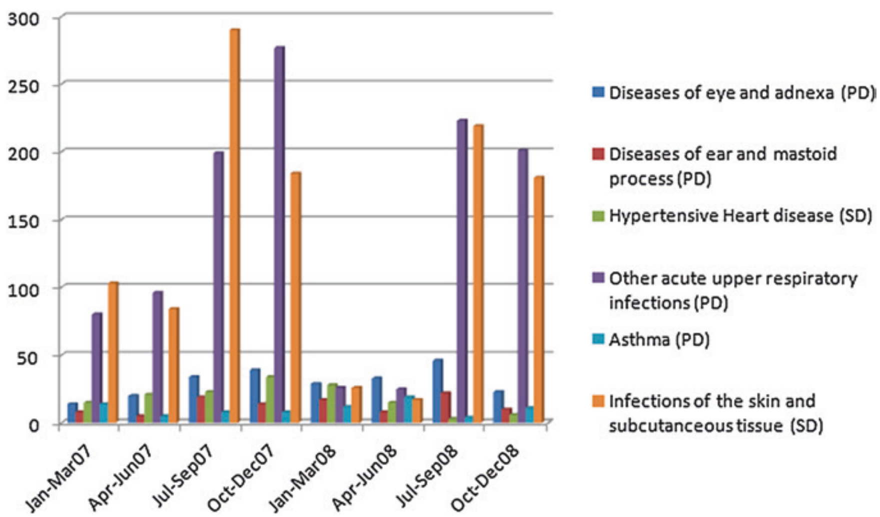

Fig. 3.1 Number of patients treated in the village dispensary Ajnauda Kalan. *Source* Based on primary information collected from village dispensary Ajnauda Kalan by our field survey team

(Table 3.19). In addition there were few examples where a family member had to be hospitalized for three to four days and additional expenditure was incurred. Table 3.20 presents the total medical expenses incurred due to health problem caused by crop stubble burning. Members suffering from smoke related chronic

Table 3.19 Expenditure incurred due to problems faced during the crop stubble burning

Problem		Dhanori	Ajnauda Kalan	Simro	Aggregate
Family members visited local doctor during Oct–Nov, 2008	Average no of members per household	2.93	2.12	2.82	2.63
Prescribed to any medicine during the 2 months of stubble burning (Oct–Nov, 2008)	Average no of members per hh	2.93	2.15	2.82	2.64
	Avg no of days per hh	13.3	13.75	11.43	12.92
	Avg amount spent per hh Rs.	280.33	335.77	504.76	360.26
Any member hospitalized during the 2 months of stubble burning (Oct–Nov, 2008)	Average no of members per hh	0.00	1.00	3.00	2.00
	Avg no of days per hh	0.00	3.00	5.00	4.00
	Avg amount spent per hh Rs.	0	300	1,000	650

and non-chronic diseases observed that their problem becomes acute and the severity increases during the time of crop stubble burning. On an average, households spent around more than a thousand Rupees on the non-chronic respiratory diseases like coughing, difficulty in breathing, irregular heartbeat, itching in eyes decreased lung function etc., during the year 2008–2009.[5] However, out of this total expenditure, around 40–50 % was spent during the months of October and November during the time of crop stubble burning. There was an additional cost in terms of household members remaining absent from work due to illness (Table 3.20).

Some respondents pointed out that Punjab government from time to time advises farmers not to set their field on fire. It is advertised in the local newspapers to make people aware about the adverse effects of crop stubble burning. Some respondents pointed out that District Commissioner directed *gram panchayats* to prevent stubble burning (Table 3.21). The administration even makes such announcements by loud speaker in the villages. However, no documentary or road shows were organized in this regard. Similarly, those farmers who incorporate stubble instead of burning it were not provided with any incentive from the administration. Although farmers were not aware about the invention of happy seeder which can provide alternate to burning, significant majority of them showed interest to buy such machine if the Punjab government gives sufficient financial support for such machine given the price of happy seeder exceeds Rs. 1 lakh in the market. The farmers indicated that if at least half of the price is born by the government for happy seeder they would be interested to buy the happy seeder machine.

[5] It should not be considered as the full cost of treatment since many of the patients are treated in public funded institutions or government hospitals where treatment is highly subsidized.

Table 3.20 Medical expenses incurred due to health problem caused by crop stubble burning

Village name	Medical Expenses incurred during the last year (Apr 08 to Mar 09)		Percentage of affected members observing severity of problem increasing at the time of crop stubble burning	Medical Expenses incurred due to acute problem during the crop stubble burning (Oct–Nov 08)				Absence from work for each illness during Oct–Nov 2008	
	Chronic disease (Rs. per affected member)	Non chronic disease (Rs. per affected member)		Doctor/ Hospital/Other charges (Rs. per affected member)	Medicine cost (Rs. per affected member)	Transportation/ freight (Rs. per affected member)	Self medication (Rs. per affected member)	(No of days per affected member)	Money loss (Rs. per affected member)
Dhanori	1,667	767	100.00	71	162	77	80	3	300
Ajnauda Kalan	1,750	1,978	97.30	159	222	80	56	5	600
Simro	2,000	478	95.45	116	200	71	92	10	1,000
Total	1,750	1,145	97.75	119	196	77	82	5	610

Table 3.21 Percentage of households saying yes to the following questions

Problem	Dhanori	Ajnauda Kalan	Simro	Aggregate
Are respondents aware of the Punjab government's policies towards pollution?	12.00	16.00	10.20	12.75
Has the Punjab government taken steps to make people aware of the adverse implications of crop stubble burning in open fields?	6.00	4.00	2.04	4.03
Have any seminars/documentary/road show being organized by the Punjab government to make people aware of the harmful effects of crop stubble burning?	0.00	2.00	0.00	0.67
Has the Punjab government given them enough incentives to stop burning the crop waste?	0.00	0.00	0.00	0.00
Are respondents aware of the happy seeder technology for getting rid of the crop stubble?	0.00	0.00	0.00	0.00
Have respondents been provided subsidy to purchase the happy seeder technology?	0.00	0.00	0.00	0.00
Are respondents willing to buy the happy seeder technology if given the financial support by the Punjab Government	73.17	35.42	41.30	48.89
How much amount of subsidy respondents think the Punjab Government should provide given the market price of happy seeder (% amount of subsidy)	50.00	50.00	50.00	50.00

3.5 Methodology

3.5.1 Theoretical Model

Air quality affects the utility of individuals and an economic value exists. There are several ways to capture this economic value, viz., dose-response, revealed preferences and contingent valuation methods. The dose-response method assumes a relationship between air quality and morbidity (and/or mortality). It puts a price tag on air quality without retrieving people's preferences for the good. But, such type of mechanical relationship of the dose response function does not take into account consumer behavior. The revealed preference methods assume that the consumers are aware of the costs/benefits of air quality and are able to adjust their behavior to reveal their preferences. This necessitates the need to have estimates of willingness to pay (WTP) or willingness to accept (WTA) on the basis of a consumer choice models aimed at measuring the strength of association between health effects and contaminated air quality.

Suppose an individual maximizes his/her utility through expenditure on marketed goods and services, X.[6] The utility depends not only on X but also on the state of health, H of an individual which is affected by the level of air quality (non-marketed good). It is further assumed that the contaminated air quality, P is beyond the control of individuals, but individuals can at least partially reduce its effects through incurring defensive expenditure, D. The utility function is defined as:

$$U(X, D; P) = H(D, P)U(X) \tag{3.1}$$

where $U_X > 0$, $U_{XX} < 0$, $H_D > 0$, $H_P < 0$, $H_{DD} < 0$, $H_{PP} < 0$.

The state of health affects individual's work performance and hence the wage income. Moreover, it is also possible that the contaminated air quality make the individual so sick as to be completely incapacitated. During the time the individual is under this condition, he/she is absent from work and loses the wage income completely. Therefore 'sick time', S can also be assumed to be the function of defensive expenditure and contaminated air quality,

$$S = S(D, P) \tag{3.2}$$

where $S_D < 0$, $S_P > 0$, $S_{DD} > 0$, $S_{PP} > 0$

The Eq. (3.1) is maximized subject to the following constraints:

The time constraint is:

$$W + S = T \tag{3.3}$$

where W is the work time and T is the total time available. The income (resource) constraint is:

$$I + wH(D, P)W \geq mS + D + X \tag{3.4}$$

where, mS is the medical expenses which are assumed proportional to illness, S, I denotes non-wage income and w is referred as wage rate.

The Lagrangian of the problem is:

$$\Pi = H(D, P)U(X) + \lambda[I + wH(D, P)(T - S) - D - X - mS] \tag{3.5}$$

The first-order optimization conditions are:

$$\begin{aligned} \Pi_X &= H(D, P)U_X - \lambda = 0 \\ \Pi_D &= H_D U + \lambda H_D wW - \lambda HwS_D - \lambda - \lambda mS_D = 0 \end{aligned} \tag{3.6}$$

Using the envelope theorem, Harrington et al. (1989) obtain the individual willingness to pay (WTP) as:

$$WTP = -\left(\frac{H_D U}{\lambda} + H_D wW\right)\frac{H_P}{H_D} + (HwS_D + mS_D)\frac{S_P}{S_D} \tag{3.7}$$

[6] Harrington et al. (1989) take the individual utility as a function of expenditure on marketed goods and services, X and leisure time, L. Since in developing countries especially in rural areas people are living in the conditions of poverty, therefore, we assume that the individual utility is the function of marketed goods and services, X only.

and the marginal loss of social welfare (SW) associated with individual responses to deterioration in air quality, therefore, is:

$$
\begin{aligned}
\frac{\partial SW}{\partial P} &= -\frac{U}{\lambda}\frac{dH}{dP} \quad \text{(Direct disutility of illness)} \\
&\quad -w \times W\frac{dH}{dP} \quad \text{(Lost work productivity)} \\
&\quad -Hw \times W_P \quad \text{(Value of lost time during illness)} \\
&\quad +m\frac{dS}{dP} \quad \text{(Medical expenses)} \\
&\quad +D_P \quad \text{(Defensive expenditure)}
\end{aligned} \tag{3.8}
$$

Equation (3.8) shows that the cost of illness caused by the contaminated air can be grouped into five categories. The term direct disutility is very subjective and it is very difficult to find its monetary value. The second term, the lost work productivity measures the value of loss caused by the illness due to lower work productivity. This loss is caused when the sick person is present for work but is not able to work with his/her full productivity. The third term measures the loss in social welfare due to illness absence of individuals from work. The last two terms measure the expenses individual have to incur for defensive and mitigating activities due to contamination of air quality. In rural areas during survey we could not get figures on the defensive activities of individuals, therefore we measures only two values: medical expenses and value of lost time during illness. Thus our measure of social loss due to contaminated air provides the lower bound of the value.

3.5.2 Estimation Strategy

To get the estimates of social welfare loss due to contaminated air in terms of health damages, we estimate the following two equations consisting of demand function for medical expenses (*mS*) and the workdays lost due to illness (S):

$$
\begin{aligned}
mS &= \alpha_0 + \alpha_1 SPM + \alpha_2 SO_2 + \alpha_3 SMOKING + \alpha_4 DRINKING + \alpha_5 PerCapitaAssets \\
&\quad + \alpha_6 SEX + \alpha_7 AGE + \alpha_8 EDUCATION + \alpha_9 OCCUPATION + \varepsilon_1
\end{aligned} \tag{3.9}
$$

and

$$
\begin{aligned}
S &= \alpha_0 + \alpha_1 SPM + \alpha_2 SMOKING + \alpha_3 DRINKING + \alpha_4 PerCapitaAssets + \alpha_5 SEX \\
&\quad + \alpha_6 AGE + \alpha_7 EDUCATION + \alpha_8 OCCUPATION + \varepsilon_2
\end{aligned} \tag{3.10}
$$

where:

Medical Expenses (mS)	Mitigating activities or medical expenses include expenses incurred as a result of air pollution related diseases. These expenditures include costs of medicine (formal as well informal), doctor's fee, diagnostic tests, hospitalization, and travel to doctor's clinic during the rice harvesting 2 months
Workdays Lost (S)	S represent the number of workdays lost per person during the two rice harvesting months of October and November due to diseases/symptoms associated with air pollution
Particulate matter (PM_{10}) and Sulfur Dioxide (SO_2)	These are the averages of the ambient emission levels observed during the monitoring period measured in $\mu g/m^3$
SMOKING	Measured as dummy variable equal to 1 if the individual is having smoking habit, otherwise 0
DRINKING	Measured as dummy variable equal to 1 if the individual is having alcohol drinking habit, otherwise 0
PerCapitaAssets	Measured in Indian rupees
SEX	Measured as dummy variable equal to 1 for male and 0 for female
AGE	Age of the individual measured in number of years
EDUCATION	Is coded as follows: 1 = Illiterate; 2 = below primary; 3 = Primary; 4 = Middle; 5 = Secondary/Metric; 6 = Technical; 7 = Graduate; 8 = Post graduate and above
OCCUPATION	Measured as dummy variable equal to 1 if the individual is in the occupation of self farming or agricultural labourer, 0 otherwise

Note that the dependent variable in Eq. (3.9) is a censored variable, i.e., the dependent variable is zero for corresponding known values of independent variables for part of the sample. Therefore, we use Tobit model for estimating the demand for mitigating activities:

$$\begin{aligned} mS_i &= \alpha + \beta x_i + u_i \quad \text{if } RHS > 0 \\ &= 0 \quad \text{otherwise} \end{aligned} \tag{3.11}$$

where mS_i refers to the probability of the ith individual incurring positive medical expenditure and x_i denotes a vector of individual characteristics, such as assets, age, sex, education, pollution parameter etc.

In Eq. (3.10) the dependent variable is a count of the total number of workdays lost due to air pollution related illness by an individual during the particular period; therefore, there are zeros for many observations. In this case Poisson regression model is appropriate as it considers the predominance of zeros and the small values and the discrete nature of the dependent variable. The least square

Table 3.22 Variables used in the analysis

Variable	Mean	Standard deviation	Maximum	Minimum	Percent
Formal medical expenses	39.26	165.05	2,700.00	0.00	
Informal medical expenses	19.46	66.62	450.00	0.00	
Workdays lost	0.06	0.72	15.00	0.00	
Age	31.35	18.50	90.00	1.00	
Education	3.14	1.77	8.00	1.00	
Per capita assets	64,469	78,377	539,467	250	
Male					54.41
Occupation (farmers and agricultural laborers)					26.32
Smoking					2.12
Drinking					5.88
Toxicants					3.29

and other linear regression models do not take into account these features. The Poisson regression model can be stated as follows:

$$prob(Y_i = y_i/x_i) = \mu_i^{y_i} e^{-\mu_i}/y_i, y_i = 0, 1, 2, \ldots \tag{3.12}$$

This equation is non-linear in parameters; therefore, for estimation purpose by taking its natural log we convert it into an equation which is linear in parameters. Note that the Poisson regression model is restrictive in many ways. For example, the assumption that the conditional mean and variance of y_i, given x_i are equal, is very strong and fails to account for over dispersion.[7] Table 3.22 gives the descriptive statistics of the variables used in the estimation of the models.

3.6 The Model Results

Tables 3.23 and 3.24 provide the results of parameter estimates of reduced form equations of mitigation expenditure and workdays lost. In the reduced form these equations are expressed as functions of a common set of socio-economic variables and ambient air pollution expressed in terms of particulate matter (PM_{10}) and SO_2 levels.

The parameter estimates of mitigating expenditure equation are given in Table 3.23. We find there is a positive and statistically significant (at 10 % level) association between ambient PM_{10} level and the mitigating expenditure.[8] This implies that individual have to spend higher amount of money to mitigate the adverse health effects when the particulate level is higher in the ambient environment. The relationship between mitigating expenditure and ambient SO_2 level is negative and statistically insignificant, as contrary to expectations. This might be happening as the ambient SO_2 level is within the NAAQS limits in the villages of Punjab.

7 Similar estimation procedure is followed by Gupta (2008).

8 Farmers take precautionary medical expenses in anticipation of the environmental pollution due to straw burning.

Table 3.23 Tobit equation of total medical expenditure (left censured at 0)

Independent variable	Coefficient
PM_{10} (+)	0.046 (1.72)*
SO_2 (+)	−5.16 (−0.52)
SMOKING (+)	395.14 (2.62)***
DRINKING (+)	177.94 (1.71)*
Per capita assets (+)	0.0009 (2.65)***
SEX	−41.76 (−0.57)
AGE (+)	4.13 (1.74)*
EDUCATION (−)	−9.85 (−0.51)
OCCUPATION (+)	92.58 (1.16)
Constant	−678.69 (−2.73)***
Pseudo R^2	0.014
Log likelihood	−1,262.37
Wald Chi^2 (9)	35.74***
Uncensored observations: 141	Left censored observations: 484
Total observations	625

Notes Figures in parentheses are t-values
***Significance at 1 % level; **Significance at 5 % level;
*Significance at 10 % level

Table 3.24 Poisson equation of workdays lost

Independent variable	Coefficient
PM_{10} (+)	0.008 (5.59)***
SMOKING (+)	−14.66 (−0.01)
DRINKING (+)	−0.81 (−0.79)
Per capita assets (−)	−0.00001 (−1.78)*
SEX	0.43 (1.07)
AGE	−0.011 (−0.97)
EDUCATION (−)	−0.71 (−5.07)***
OCCUPATION	−0.32 (−0.67)
Constant	−5.02 (−3.98)***
Pseudo R^2	0.023
Log likelihood	−170.93
Wald Chi^2 (8)	97.97
Total observations	625

Notes Figures in parentheses are t-values
***Significance at 1 % level; **Significance at 5 % level;
*Significance at 10 % level

As is expected, the coefficient of the variables such as smoking and drinking behaviour of the individual are found to be positive and statistically significant. These personal habits coupled with the ambient air pollution make individual more prone to asthmatic diseases and as a result they are required to spend more on mitigating activities. Similarly we find there is positive and significant relationship between the age of individual and their mitigating expenses implying that the marginal effect of age on mitigating expenses is positive. We also observe that there is positive and statistically significant relationship between mitigating expenses and per capita assets. This might be happening because wealthier individuals do not hesitate to take mitigating activities if they are suspected to some diseases in comparison to people who have lesser assets.

Education raises awareness level of individuals with respect to environmental problems and related health damages and helps in taking informed preventing activities related decisions. The coefficient of education is negative, as expected, though statistically insignificant, depicts that there happens to be a reduction in mitigation expenditure with the increase in education level. Similarly, the individuals who have to work in agriculture fields where burning of agricultural residue take place are thought to be more prone to the adverse effects of pollution in comparison to their counterparts who are in other occupations such as salaried individuals. We use dummy variable equal to one for farmers and agricultural wage earners and zero for the individuals who are in other occupations. We find a positive association between occupation variable and medical expenditure.

Table 3.24 presents parameter estimates of the reduced form equation of workdays lost. As expected, the coefficient of PM_{10} variable is positive and statistically significant at 1 % level implying that the probability of losing workdays increases as the concentration of particulate matters in ambient environment increases. Education increases awareness level and helps in taking preventing action and as a result an individual is expected not to lose workday, therefore, we find that there is negative association between education level of individuals and workdays lost. Similarly, wealthier individuals could spend money on preventing activities and there is negative relationship between per capita assets and workdays lost.

3.6.1 Welfare Loss

The welfare loss in terms of health damage due to increase in the concentration of particulate matters from paddy straw burning in the ambient environment can be estimated in terms of increase in the medical expenditure on mitigating activities and the opportunity cost of workdays lost and are presented in Table 3.25.

3.6.2 Increase in Medical Expenditure

To get the estimates of welfare loss in terms of increased medical expenditure we need to obtain the marginal effects. The marginal effects in the case of Tobit estimation could be computed by taking partial derivatives of mitigating expenditure equation with respect to PM_{10} and multiplying it by the probability

Table 3.25 Welfare loss due to increased air pollution in rural Punjab

	Representative individual (Rs.)	Rural Patiala District (Rs. millions)	Rural Punjab (Rs. millions)
Medical expenditure	2.17	2.35	36.52
Opportunity cost of workdays lost	2.35	2.54	39.57
Total welfare loss	4.52	4.89	76.09

of the dependent variable taking the non-zero values. If the ambient PM_{10} level is reduced from the level observed during the harvesting period of rice in rural Punjab to the safe level (i.e., a reduction of 207 μg/m^3 since the safe level defined under NAAQS is 100 μg/m^3 for the 24 h average), the estimated reduction in medical expenditure turns out to be Rs. 2.17 for the months of October and November for a representative person.

Total rural population projected for October 2008 based on Census 2001 is 1,083 thousand and 16,839 thousand for the district of Patiala and the state of Punjab, respectively. Extrapolating this welfare loss for the entire rural population of Patiala and Punjab, it is estimated as Rs. 2.35 million and Rs. 36.52 million, respectively.

3.6.3 Opportunity Cost of Increase in Workdays Lost

To get the marginal effects of reduction in PM_{10} level on workdays lost, we differentiated partially the reduced form equation of workdays lost with respect to PM_{10}. The Poisson estimates show that 1 μg/m^3 increase in PM_{10} results in a marginal loss of 0.0000946 days for a representative individual in these two harvesting months. If the PM_{10} level is reduced from the current level to the safe levels during rice harvesting period, the estimated gain in workdays is 0.03. In monetary terms, the loss in terms of workdays lost for a representative individual is estimated to be Rs. 2.35 and for rural Patiala district and rural Punjab state it turns out to be Rs. 2.54 million and 39.57 million, respectively assuming a wage rate of Rs. 120 per day.[9]

The total monetary loss (due to lost workdays and increased medical expenditures) caused in terms of health damages due to increase in ambient PM_{10} level beyond the safe level for the rural areas of Patiala district and Punjab state is estimated as, Rs. 4.89 million and Rs. 76.09 million, respectively. These losses should be considered the lower bound of health damages caused by the increased air pollution level in rural Punjab. These estimates could be much higher if expenses on

[9] A wage rate fixed for the state of Punjab under National Rural Employment Guarantee Act (NREGA).

averting activities, productivity loss due to illness, monetary value of discomfort and utility could also be considered. There is additional monetary cost of burning to the farmers in terms of additional fertilizer, pesticides and irrigation as was shown by the survey results discussed in section 4. One also has to add into the above cost the losses of soil nutrient, vegetation, bio-diversity and accidents caused because of low visibility.

3.7 Summary of the Chapter

In this chapter an attempt is made to estimate the monetary value of health damage caused by the smoke pollution emitted by the burning of rice and wheat stubble in the open fields in Punjab, India. We use data of 625 individuals collected from a household level survey conducted in three villages, namely Dhanouri, Ajnoda Kalan and Simro of Patiala district of Punjab for 150 households. To get the monetary values we estimated two equations: one with mitigation expenditure and the other with workdays lost as dependent variables. Tobit and Poisson models are used for estimating mitigation expenditure and workdays lost equations, respectively.

On an average, total amount of stubble generated for paddy and wheat per acre was around 23 and 19 quintals, respectively. Out of this in the case of paddy, more than 85 % was burnt in the open field and less than 10 % was incorporated, while rest of 8 % was used for other purposes. In the case of wheat, 77 % of the total amount was used as fodder for animals while 9 % was incorporated and around 11 % was burnt. Although farmers were convinced that burning was not harming the level of crop yield but they pointed out that burning of field added extra cost to the production because of top soil getting affected by the burning. The farmers who burnt the field (fully or partly) to clear the wheat stubble used 169 kg of urea in the next crop of paddy while those who incorporated or adopted other means used 145 and 148 kg of urea, respectively. Similarly, those farmers who burnt paddy field, used added amount of Di-Amonia Phosphate (DAP) to recapture the nutritive lost in the fire in comparison to those who incorporated or removed stubble manually. Higher expenses were not only in terms of higher fertilizer but also in terms of higher irrigation requirement by those who burn their field to clear the stubble

Our household survey showed that paddy stubble burning leads to air pollution and several other problems. Irritation in eyes and congestion in the chest were the two major problems faced by the majority of the household members. Respiratory allergy, asthma and bronchial problems were the other smoke related diseases which affected household members in the selected villages. Almost 50 % of the selected households indicated that their health related problems get aggravated during or shortly after harvest when crop stubble burning is in full swing during the months of October, November and December. In the peak season, affected families had to consult doctor or use some home medicine to get relief from irritation/itching in eyes, breathing problem and similar other smoke related problems. On an average, the affected members suffered at least half a month from such problems and had to spend Rs. 300–500 per household on medicine. In addition there were few examples where a family member had to be hospitalized for 3–4 days and additional expenditure was incurred. On an average, households spent around more than a thousand Rupees on the non chronic respiratory diseases like coughing, difficulty in breathing, irregular heartbeat, itching in eyes decreased lung function etc., during the year 2008–2009. However, out of this total expenditure, around 40–50 % was spent during the months of October and November during the time of crop stubble burning. There was an additional cost in terms of household members remaining absent from work due to illness.

We find that total annual welfare loss in terms of health damages due to air pollution caused by the burning of paddy straw in rural Punjab amounts to Rs. 76 millions. These estimates could be much higher if expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility could also be considered. There is additional monetary cost of burning to the farmers in terms of additional fertilizer, pesticides and irrigation. One also needs to add the losses of soil nutrient, vegetation, bio-diversity and accidents caused because of low visibility.

Appendix

See Tables 3.26 and 3.27.

Table 3.26 Cropping pattern of selected farmers (percentage of gross cropped area)

Crop name	Marginal	Small	Medium	Large	Total
Wheat	40.3	27.4	25.2	25.2	28.5
Rice	33.8	27.4	25.2	25.2	27.3
Maize	0.0	0.0	0.0	0.9	0.2
Moong	0.0	0.0	0.0	0.9	0.2
Mustard	0.0	0.0	0.0	0.9	0.2
Sugarcane	0.0	0.0	0.0	0.9	0.2
Jowar and bajra (kharif green fodder)	16.9	23.0	25.2	23.5	22.6
Barseem (rabi green fodder)	9.1	22.1	24.3	22.6	20.4
Total	100.0	100.0	100.0	100.0	100.0

Table 3.27 Are there any buyers of rice/wheat residue

	Dhanori	Ajnauda Kalan	Simro	Aggregate
Are there any buyers for rice residue (percent of hh)	0.00	4.00	2.00	2.00
Are there any buyers for wheat residue (percent of hh)	10.00	16.00	10.00	12.00
Quantity of rice residue sold by households (quintals per hh)	0.00	2.50	5.60	2.80
Quantity of wheat residue sold by households (quintals per hh)	2.38	9.36	6.70	6.15
Average price of rice residue (Rs. per quintals)	10.00	10.00	10.00	10.00
Average price of wheat residue (Rs. per quintals)	200.00	200.00	200.00	200.00

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