Does commercial farming protect the environment? Evidence from chemical input use in Haryana, India

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Abstract

***Purpose*:** This study investigates the impact of contract farming (CF) on chemical input usage (fertilisers, pesticides and herbicides) in wheat farming in Haryana, India, weighing on environmental risks from unsustainable chemical input usage under CF.

***Design/methodology/approach*:** The research employs an endogenous switching regression (ESR) model using data from 754 farm households, enabling a comparative analysis between contract and non-contract farmers.

***Findings*:** The results show that farmers who adopted CF would have reduced chemical input usage by 26.8% if they did not adopt it. Conversely, non-adopters would have increased chemical input usage by 54% if they adopted CF. While CF enhances farm productivity and income, it also increases chemical input usage, posing risks such as soil fertility loss and water contamination.

***Originality*:** This study addresses the overlooked topic of chemical input usage in CF research. Leveraging household data and using an endogenous switching regression model provides unique comparative analysis and counterfactual scenarios. The findings contribute to understanding the environmental implications of CF and propose actionable recommendations for sustainable agricultural practices.

***Managerial or Policy implications*:** The study recommends promoting organic farming and minimal chemical usage in CF agreements. Government intervention is needed to reduce the environmental impact of CF. Policies should promote environment-friendly fertilisers and provide guidelines on chemical usage based on crop variety, seed quality and soil fertility.

***Research limitations/implications*:** The geographic focus on Haryana may limit generalisability. Reliance on cross-sectional data from a single season might not capture variability across different seasons. Future research could expand to other regions, use longitudinal data and investigate a broader range of crops.

Keywords: Contract farming; Chemical inputs; Endogenous switching regression; Haryana, India

1 Introduction

Agriculture has long been acknowledged as a critical factor in the economic growth of developing countries (Akber and Paltasingh, 2021; Henningsen *et al.*, 2015). It is widely known that the productivity of the agricultural sector in emerging nations is usually lower than that of non-agricultural sectors in the same country or agricultural sector in other developed nations (Imai *et al.*, 2015). Many factors contribute to this low agricultural productivity—lack of knowledge about productivity-augmenting farm practices and highly productive technologies, lack of accessibility to or limited availability of highly productive' varieties of inputs, lack of liquidity or restricted access to credit and a hesitancy to invest in productivity-augmenting measures due to price uncertainty, production risk and irregular market conditions paired with poor farmers' risk aversion (Mpeta *et al.*, 2018; Zhou *et al.*, 2024). The farm sector growth may be attained by improving resource utilisation efficiency. Most of the earlier approaches have tried to address expansion by increasing the use of agricultural inputs and growing farming corporations by putting additional areas under cultivation rather than concentrating on maximising the effective use of currently available resources (Dube and Mugwagwa, 2017). The presence of government support also contributes to reducing agricultural inefficiencies (Bhattacharyya and Mandal, 2014).

In this context, contract farming can be considered an effective strategy to augment farm productivity and income of the farming community. In fact, it is an institutional arrangement that reduces overall farm uncertainty, says Das and Bhattacharya (2024). However, it is observed that agribusiness firms promote high-valued commodities that require more chemicals and have, ultimately, direct as well as indirect impacts on the environment. Over-utilisation of chemicals leads to air pollution, soil quality degradation, water eutrophication and toxicity, groundwater pollution, and even change the ecosystems (Amin and Jilani, 2024; Bijay-Singh and Craswell, 2021; Rahman and Zhang, 2018; Tong and Clarke, 2020). In addition, the presence of metals in many agricultural chemicals has raised concerns that long-term use may lead to hazardous concentrations in the soil. These highly contaminated fertilisers have the potential to poison water and soil resources, infiltrate the food chain through crop plants and eventually have an adverse effect on the health of people and animals (Dhankhar and Kumar, 2023; Savci, 2012). Hence, these scenarios raise concerns about the viability of contemporary agriculture.

In India, a considerable body of literature exists that looks at how contract farming affects farmers' earnings, productivity, efficiency, food security, production risks, etc. (Dsouza *et al.*, 2023; Gersch, 2018; Kaur and Singla, 2018; Meti *et al.*, 2016; Mishra *et al.*, 2018; Saroj *et al.*, 2023; Saroj and Paltasingh, 2024; Sharma, 2016). However, its environmental and health impacts through the unrecommended and unsustainable usage of chemical inputs, such as chemical fertilisers, pesticides and weedicides, have been largely overlooked. To our knowledge, limited Indian studies (Mishra *et al.*, 2021) have simultaneously linked contract farming, chemical usage and environmental risk. Therefore, we attempt to answer the research question of what the impacts of contract farming are on the usage of chemical inputs in wheat farming in Haryana and how this impacts environmentally sustainable agricultural practices. Our study strengthens the existing literature by evaluating the effect of contract farming on environmentally sustainable agricultural behaviours by using household data of 754 Indian farmers conducted during 2019-20. Precisely, this study aims (1) to conduct a comparative estimation of chemical input usage in wheat farming across groups of contract and non-contract producers in Haryana and (2) to check the impacts of contract farming on chemical usage on both contract and non-contract producers through observed and counterfactual cases. The observed cases are actual average values of chemicals used by contract farming adopters and non-adopters, while counterfactual cases are when contract farming adopters do not adopt and/or non-adopters adopt the contract farming. Thus, taking these estimates, we calculate the treatment effect of contract farming on chemical inputs for contract farming adopters and non-adopters under wheat farming. Based on the findings, the study suggests some policy recommendations for sustainability to improve wheat growers' productivity in Haryana.

This study makes several contributions to existing literature. First, it addresses the usage of chemical inputs, an issue that has been largely overlooked in prior contract farming research. Second, by leveraging household data, the study provides a comparative analysis of chemical input usage between contract and non-contract farmers. Third, this research estimates both the observed usage of chemical inputs by contract farming adopters and constructs counterfactual scenarios, thereby offering a clear understanding of the treatment effect of contract farming on organic farming practices. Last, it proposes doable recommendations to encourage environmentally sustainable practices among wheat growers of Haryana.

The remaining sections of the paper are arranged as follows: Section 2 presents a summary of the data sources, outlines the empirical methodology and elaborates on the analytical framework;

Section 3 presents a discussion of the results obtained from the analysis; and finally, Section 4 concludes by offering policy prescription based on the findings.

2 Material and method

2.1 Data sources and variables

The present study is based on cross-sectional data collected from two districts of Haryana—Hisar and Sirsa districts. We collected the data during the Kharif season of 2019-20. The sample included a total of 754 wheat farmers, consisting of 323 from contract farming (CF) and 431 from non-contract farming (NCF). Hisar and Sirsa districts were selected as study regions because they both account for the largest share of the state's wheat production (GOH, 2019a, 2019b). Under both districts, a multistage purposive sampling method was adopted, where we first took the list of wheat growers involved in CF from the related contracting firms. The provided list featured specific details about the farmers, i.e., their farm area (in acres) under CF, varieties of crops they cultivated, etc., because they are the final unit of study. A scheduled questionnaire was used to gather all information about wheat growers' socio-economic, demographic and other farm-specific features. In addition, we collected some qualitative data through group discussions with experienced farmers in each village to cross-check the gathered information.

Table 1 gives the descriptive statistics of all variables based on the field survey of 2019. One important dependent variable that estimates the selection equation (described in Section 2.2) is a dummy variable that defines the adoption of commercial farming. So, it is a dichotomous variable where 1-CF adoption and 0-otherwise. The main outcome variable is chemical use. Under this, we have taken both chemical fertilisers and pesticide use (kg/acre) and taken the consolidated figure as kg per acre. So, we have used this chemical in both commercial and conventional farming.

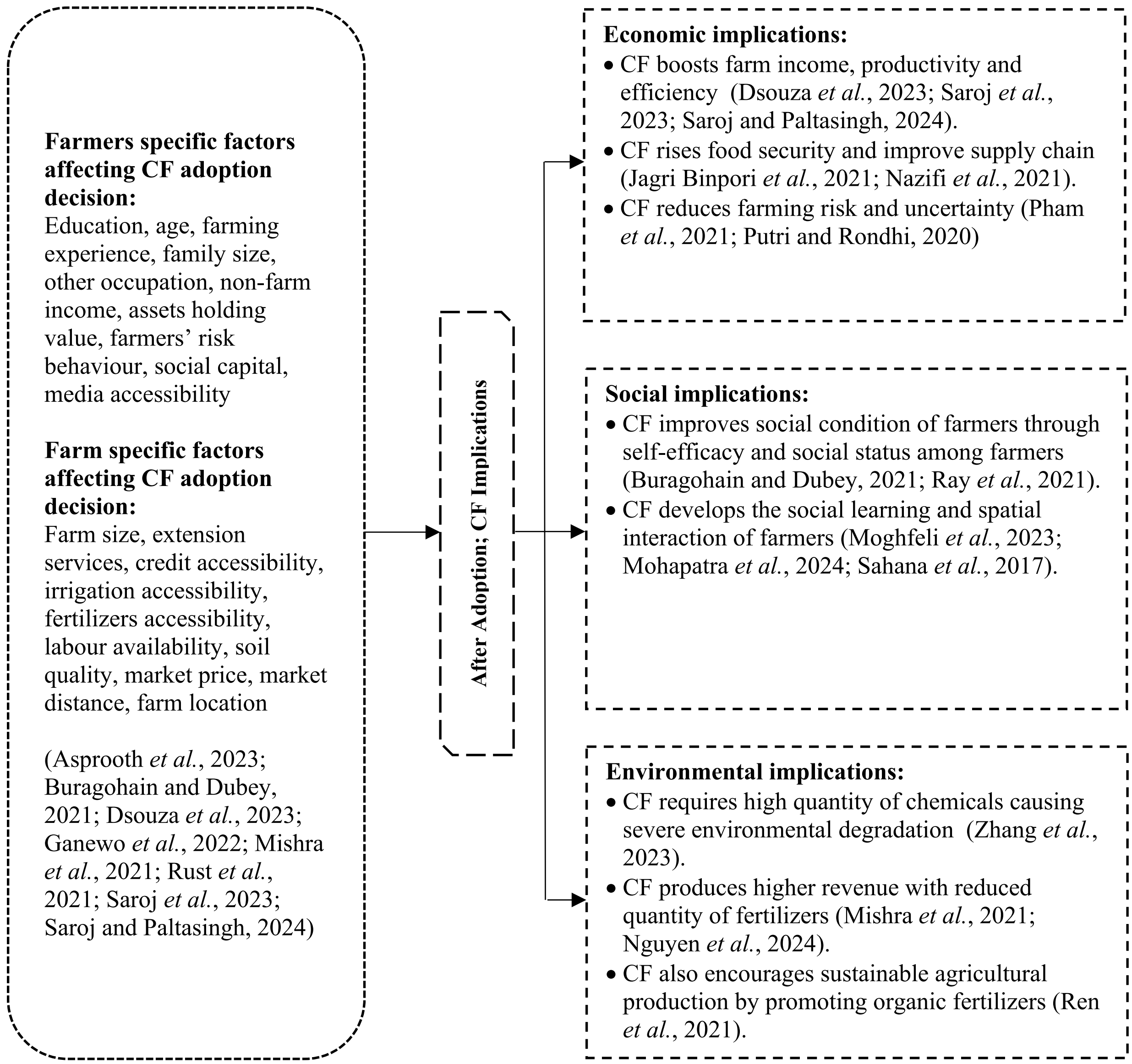
Table 1. Definition of variables and their descriptive statistics

Variables	Descriptions	Mean		Std. Dev.	
		CF	NCF	CF	NCF
Dependent variables					
CF adoption	Adoption of CF (1-yes, 0-no)	1	--	0	--
Chemical input usage	Used quantity of fertilisers and pesticides (kg/acre)	272.4	188.2	63.3	27.11
Independent variables					
EXP	Years of farming experience of head (number)	25.09	26.85	8.77	9.56
EDU	Years of schooling of head (number)	10.04	7.19	4.44	4.9
FS	Total number of household members (number)	5.57	5.32	1.06	0.95
NF	Total income from non-farm activities (Rs in lakhs)	1.36	0.9	1.32	0.98
AREA	Total household landholding (acres)	13.99	7.22	7.7	4.89
CRD	Credit accessibility (1-yes, 0-no)	0.71	0.67	0.45	0.46
EXT	Extension accessibility (1-yes, 0-no)	0.66	0.13	0.47	0.34
SEED	Quantity of seeds applied (kg/acre)	41.65	50.32	3.62	5.01
LBR	Numbers of labour used (number)	6.76	5.88	0.88	0.73
IRR	Number of irrigations used (number)	6.12	5.74	0.32	0.68
DF	Distance to agribusiness firm (km)	34.3	34.63	17.6	13.69
DM	Distance to open market (km)	33.04	30.42	16.6	11.77
SOIL	Soil quality dummy (1-good, 0-otherwise)	0.95	0.91	0.19	0.27
MEDIA	Media access dummy (1-yes, 0-no)	1.00	0.88	0.00	0.32
MBR	Member of any developmental /Cooperative organisation (1-yes, 0-no)	0.01	0.01	0.12	0.10
ASS	Total value of owned farming assets (Rs in lakhs)	3.20	2.05	1.73	2.17

Source: Authors own work.

Among all explanatory variables, farming experience, education and household size are defined in terms of years of farming, years of schooling and number of members, respectively. So, these are discrete variables. Non-farm income is defined in terms of rupees annually, and landholding is the total acres of owned land under operational holding. Labour and irrigation are measured in frequency (number). Similarly, other discrete variables are distance to the contracting firms (km), local town (km), seed use (kg/acre), etc. The rest are dummy variables, such as social capital, soil quality and media. Expected CF implications of study variables are demonstrated in Figure 1.

Figure 1. Implications illustration of study variables

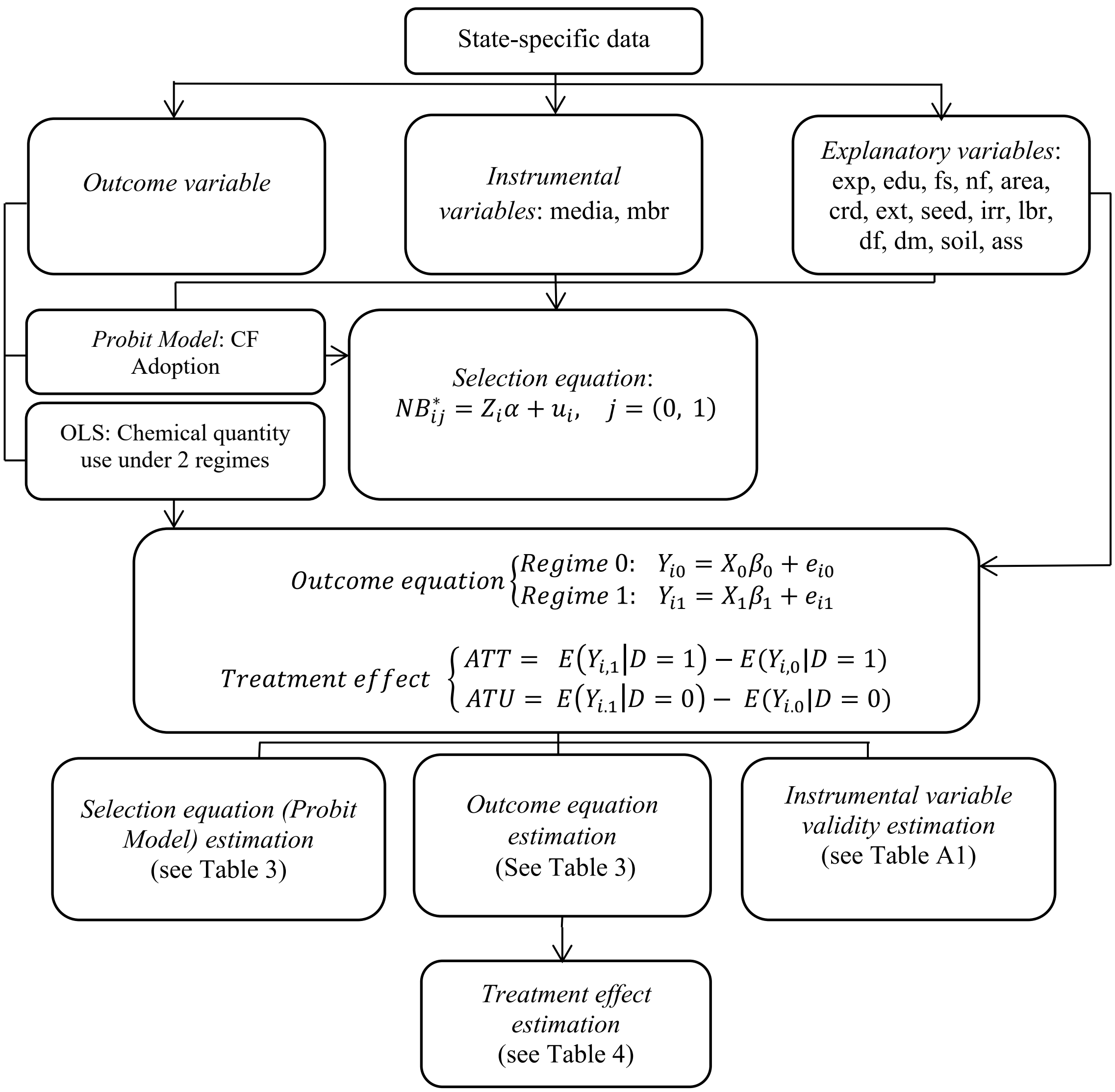


Source: Authors own work.

2.2 Empirical model

An endogenous switching regression (ESR) method is applied to examine the treatment effects of commercial farming on the usage of chemical inputs. The propensity score matching (PSM) method is often used in literature to illustrate the welfare implication of adopting new technology. The PSM approach, however, addresses selection bias arising from observables, yet it is unable to address bias associated with unobserved features that influence adoption choices (Akber and Paltasingh, 2023; Bairagi *et al.*, 2020; Mishra *et al.*, 2021). Remarkably, the PSM limits conclusions by presuming that adopters and non-adopters have the same personal traits. Nonetheless, the ESR model is used in this work since it reduces selection bias and other issues. We can understand the overview of this method with the help of Figure 2.

Figure 2. Methodological flowchart



Source: Authors own work.

The ESR model comprises a selection equation in the first stage that determines farmers' adoption behaviour, i.e., whether a farmer adopts CF or not. Depending on the adoption criterion, two separate outcome/regime equations are estimated to find the outcome variables in the second step. The selection equation presents the CF adoption decision as binary: 1 if adoption is desired and 0 otherwise. This selection equation in the first step is estimated with a probit model. Farmers adopt only if $NB_{i1}^{*} > NB_{i0}^{*}$, not otherwise. The unobservable adoption variable, NB_{ij}^{*}, can be expressed in the following latent variable model as a function of a few observable factors:

$$NB_{ij}^{*} = Z_i\alpha + u_i, \quad j = (0,\ 1) \tag{1}$$

So, $\begin{cases} NB_i = 1 \ \text{ if } \ NB_{i,1}^{*} > NB_{i,0}^{*} \\ NB_i = 0 \ \text{ if } \ NB_{i,1}^{*} \leq NB_{i,0}^{*} \end{cases}$

where, Z_i is the vector of explanatory variables, including farmer and farm-specific factors and other demographic characteristics of farmers. Similarly, α is the vector of parameters to be evaluated and u_i is the random error term. Consequently, determined by the selection function, two outcome equations are defined below for the second stage:

$$\begin{cases} \text{Regime 0:} \ \ Y_{i0} = X_0\beta_0 + e_{i0} \\ \text{Regime 1:} \ \ Y_{i1} = X_1\beta_1 + e_{i1} \end{cases} \tag{2}$$

where, Y_{ij} is the outcome variable for CF adapters (Y_{i1}) and CF non-adopters (Y_{i0}); X_j represents a vector of explanatory factors; β_j is a vector of parameters that need to be evaluated, and e_{ij} is the random error term. Detailed information on the ESR approach can be drawn from Lokshin and Sajaia (2004) and Fuglie and Bosch (1995).

Exclusionary limitations must be employed to validate the model. So, we require instrumental variables that are directly linked to CF adoption rather than the outcome variables. Based on the literature (Bairagi *et al.*, 2020; Dsouza *et al.*, 2023; Mishra *et al.*, 2018), we have incorporated two instrumental variables in the ESR framework (i.e., access to media and social capital). These variables are information sources that influence the choice to contract adoption but do not directly affect chemical usage levels. Therefore, they are considered exogenous. We run a simple falsification test for these two instruments' exclusion restriction and permissibility. Table A1 (Appendix) shows the validity test results for instrumental variables. We find that these two variables are significant determinants of adoption decision individually and also jointly (Wald's chi-squared value = 72 and P value = 0.00), but these instruments are not significant determinants of outcome variables (chemicals use) as we find the F-stat is 0.045 and 0.036 in the case of both adopters and non-adopters. So, these are relevant instruments because they affect the outcome variable only through the adoption decision (selection equation).

2.3 Conditional expectation and treatment effect

After fixing the selection problem of instruments and their validity to tackle endogeneity bias in the model, we further estimated the expected quantity of chemicals used in the case of CF and NCF. We estimated the expected chemical inputs used in both observed and counterfactual cases for CF adopters and non-adopters. The counterfactual estimates relate to their hypothetical situations, such as if adopters do not adopt and non-adopters adopt. The conditional expectations of these four cases for two groups are specified below:

Farmers with CF adoption (observed):

$$E(Y_{i1}|D = 1) = X'\beta_1 + \sigma_{u1}\lambda_{e1} \quad (3a)$$

Farmers with CF non-adoption (counterfactual):

$$E(Y_{i0}|D = 1) = X'\beta_0 + \sigma_{u0}\lambda_{e1} \quad (3b)$$

Farmers with CF non-adoption (observed):

$E(Y_{i0}|D=0) \; = \; X'\beta_0 + \sigma_{u0}\lambda_{e0}$ (3c)

Farmers with CF adoption (counterfactual):

$E(Y_{i,1}|D=0) \; = \; X'\beta_1 + \sigma_{u1}\lambda_{e0}$ (3d)

Equations (3a) and (3c) represent the observed outcomes, whereas Equations (3b) and (3d) represent their counterfactual outcomes. Following Carter and Milon (2005) and Lokshin and Sajaia (2004), we calculate the net effect of CF on chemical inputs usage for adopters (the average treatment effect on treated or ATT) and non-adopters (the average treatment effect on the untreated or ATU). This ATT reveals the inducement effect of commercial farming on the level of chemical inputs used by those farmers adhering to commercial farming. Similarly, ATU reveals the treatment effect in the form of chemical uses for non-commercial farmers.

The difference between Equations (3a) and (3b) can be used to calculate ATT:

ATT = $E\left(Y_{i,1}\middle|D=1\right) - E(Y_{i,0}|D=1)$ (4)

Similarly, the difference between Equations (3d) and (3c) can be used to calculate ATU:

ATU = $E\left(Y_{i,1}\middle|D=0\right) - E(Y_{i,0}|D=0)$ (5)

The expected results provided by Equation (3a-3d) can also be used to determine the base heterogeneity effect of CF. For the farmers who decide to adopt CF, the difference between Equations (3a) and (3d) is referred to as the base heterogeneity effect:

BH1 = $E(Y_{i1}|D=1) - E(Y_{i,1}|D=0)$ (6)

Similarly, for those who decide not to adopt CF, the difference between Equations (3b) and (3c) is referred to as the base heterogeneity effect:

BH0 = $E(Y_{i0}|D=1) - E(Y_{i0}|D=0)$ (7)

At last, following Asfaw et al. (2012), we estimate the transitional heterogeneity (TH), showing that the impacts of CF are different for actual adopters and counterfactual adopters. The difference between Equations (4) and (5) can be used to calculate TH.

3 Result and discussion

3.1 Mean difference of covariates

Table 2 shows the mean difference in farm major features between the two groups, CF and NCF. Gross margin, net margin and yield are crucial factors that differentiate CF adopters from non-adopters. The differences between gross margins and net margins are Rs 8998.02 and 7529.97 per acre, respectively. Moreover, the yield difference is 1.42 quintals per acre. These all indicate that CF adopters earn more revenue than their counterparts (Danso-Abbeam *et al.*, 2024; Lin and Chang, 2021). Notably, on average, CF adopters own around 14 acres of land area, which is almost double that of non-adopters (7.22 acres). We also observed that adopters use significantly more fertiliser and pesticides than non-adopters. The difference is about 83 kg/acre and 1 litre/acre, respectively, indicating that CF requires more quantity of these inputs than conventional farming. In fact, CF requires the recommended doses of inputs used, resulting in a little higher use of these inputs than in conventional farming. These results are supported by Adabe *et al.* (2019) on rice farming in Togo.

Similarly, seed quantity is also used according to recommendation where the mean difference is about 9 kg/acre. A significant difference is observed between the mean value of seeds cost, fertiliser cost, pesticides cost and other production costs. The cost of growing wheat is relatively higher for CF than NCF. The mean differences of these major factors are significant at the 1% level. Many studies (Bidzakin *et al.*, 2020; Cahyadi and Waibel, 2016) also found almost similar results for different crops in different regions. So, this mean difference test supports the fact that commercial farming augments gross and net margins and paves the way for greater use of chemical inputs like chemical fertiliser and pesticides. But this simple comparison is misleading. Therefore, we resort to treatment effects to learn how commercial farming augments chemical use in order to gain better insights.

Table 2. Mean difference in key indicators between commercial and conventional farming

	Mean Values		Mean Difference	t-value
	Adopters	Non-Adopters		
Gross margin per acre (Rs)	45762.66	36764.64	8998.02	49.11***
Net margin per acre (Rs)	34307.93	26777.96	7529.97	32.64***
Yield per acre (quintal)	21.68	20.26	1.42	16.99***
Landholding area (acres)	13.99	7.22	6.76	14.69***
Seeds use (kg/acre)	41.65	50.32	8.67	26.36***
Fertiliser use (kg/acre)	271.45	188.27	83.18	24.53***
Pesticides use (litre/acre)	1.75	0.77	0.98	11.60***
Seed cost (Rs)	1546.59	1072.42	474.17	54.63***
Fertiliser cost (Rs)	2973.71	2464.17	509.53	22.87***
Pesticides cost (Rs)	1063.7	747.2	316.49	27.76***
Miscellaneous production cost (Rs)	5868.19	5702.82	165.37	08.65***

Source: Authors own work. *Note*: The asterisks (***) indicate 1% levels of significance.

3.2 Determinants of contract farming participation

This section shows the findings of determinants influencing CF participation in the context of chemical usage as outcome variables. First, Table 3 summarises the evaluated findings of the selection equation (factors influencing CF adoption decision) in columns 2 and 3. These results are derived by running the Probit model within the ESR outlines. Next, the determinants of chemical usage are summarised in columns 4-5 and 6-7 (in Table 3) for CF adopters and non-adopters, respectively.

The likelihood ratio test for simultaneous independence between both selection and outcome equations is significant, showing that we can reject the null hypothesis of no dependency between CF participation and chemical usage. It suggests a positive correlation between CF adoption and chemical quantity. The significant correlation coefficients (ρ) for both adopters and non-adopters reveal the possible endogeneity and self-selection. Simply, the contracting impacts on the chemical usage for wheat growers, given the selection decision, is influenced by both types of factors, i.e., observed and unobserved.

The results indicate that household heads' education, non-agricultural income, landholding size, access to credit, agricultural extension, assets holding value and media access are positive and statistically significant factors of participation in CF. The favourable relationship with education means that well-educated farmers can better understand the importance and dynamics of modern farming practices like contract farming (Paltasingh and Goyari, 2018; Saroj *et al.*, 2023; Verma, 2024). Also, they are more adept at communicating their ideas and interacting with firms. Farmers with multiple sources of income and easy access to credit are more expected to opt for CF because it helps in furnishing timely inputs with better technology (Ghimire and Kotani, 2015). Farmers having contact with extension officers are usually forward-looking farmers and are more expected to adopt CF adoption (Verma and Jena, 2024). The size of the landholding also positively and significantly affects the CF adoption decision (Kumar *et al.*, 2019). In the production process, the land is a crucial resource basis for the farmer. So, farmers with a larger cultivable area are more expected to adopt new technologies (Asprooth *et al.*, 2023). Access to the media also assists in sustainable agriculture by gathering useful information, thereby leading to CF participation (Rust *et al.*, 2021). However, the distance to the agribusiness firm has negative significance since a long distance between the contracting firm and the farm discourages farmers from adopting CF. They intend to sell produce at nearby grain markets with the help of intermediaries at low prices.

Table 3. Result of endogenous switching regression for chemical usage

	CF adoption (1/0)		Chemical usage by adopters		Chemical usage by non-adopters	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
EXP	-0.065	0.171	0.037	0.029	-0.001	0.009
EDN	0.469***	0.173	-0.007**	0.019	-0.024**	0.010
FS	0.129	0.189	-0.010	0.020	-0.013	0.013
NF	0.408***	0.089	0.022***	0.007	0.015*	0.006
AREA	0.105***	0.021	-0.006**	0.001	-0.011***	0.001
CRD	0.437**	0.192	0.064*	0.019	0.003	0.012
DM	0.144	0.028	0.011**	0.002	-0.007**	0.002
DF	-0.139**	0.025	-0.011**	0.002	-0.010	0.002
EXT	1.458***	0.223	-0.062**	0.024	-0.041**	0.017
ASS	0.084**	0.042	0.019*	0.002	0.014*	0.001
SEED	-	-	0.012**	0.007	0.001*	0.001
LBR	-	-	0.033**	0.011	0.032**	0.008
IRR	-	-	0.047	0.028	0.330	0.095
SOIL	-	-	-0.124***	0.046	-0.079***	0.021
MEDIA	1.434**	0.694	-	-	-	-
MBR	-0.794	1.118	-	-	-	-
Constant	3.056***	1.791	5.445***	0.168	5.307***	0.091
Pi			-0.934	0.048	0.372	0.185
σi			0.166	0.007	0.115	0.004
No. of obs.	754					
Log-likelihood	373.15					
Prob. > χ^2	0.00					
Wald $\chi^2(12)$	310.32					
LR test of independence eq.	24.62***					

Source: Authors own work. *Note*: The asterisks (***), (**), and (*) indicate 1%, 5%, and 10% levels of significance.

3.3 Determinants of chemical inputs use

This section presents the results of determining factors of the outcome variables (chemical usage) under both CF and NCF. From Table 3, farmers' education has a negative impact on the quantity of chemical usage. In fact, years of education help them to understand the value of quality farming so they can avoid the overuse of inputs, including fertilisers and pesticides. Also, farmers with higher education are found to be more efficient and productive than less educated (Gille, 2012). Many adopters may have to rely on credits for inputs purchasing and other production costs. So, the availability of adequate credit potentially affects the quantity of chemicals used (Argaw *et al.*, 2024). Landholding size has a significantly positive impact on the quantity of used chemicals. It is observed that farmers who own more land area are more efficient than their counterparts. Hence, they can efficiently manage their farm resources and, ultimately, avoid the overutilisation of chemicals. Comparable results were also observed by Zhang et al. (2023) in China and Nguyen et al. (2024) in the Vietnam farm economy.

Moreover, agricultural extension is negatively significant, implying that farmers who are getting extension services from contracting firms or any other sources work efficiently, resulting in the best utilisation of resources. It also reduces the overutilisation or underutilisation of farm inputs, i.e., seeds, fertilisers, pesticides, irrigation and labour. However, some studies (Geffersa, 2024; Islam *et al.*, 2024) have found opposite results, stating that having extension services induces more fertiliser quantity. Distance to contracting firms for CF adopters and distance to the local market for CF non-adopters are negatively related to the quantity of chemicals used. This suggests that the longer distance between the farm area and the selling point discourages farmers from applying chemicals on their farms. It may add additional production costs through transportation, tax and levies expenditures. As a result, profit margin decreases; therefore, farmers strive to avoid making unnecessary purchases. In the same line, Akpan, Okon, and Ernest (2019), Dassa, Ifa and Gobena (2022), and Heisse and Morimoto (2024) provided evidence.

On the other hand, the quality of used seeds is negatively significant with fertiliser quantity under both CF and NCF. This implies that high-quality seeds require fewer chemicals to be used. Labour is a positively significant determinant, implying that when, sometimes, labourers are not available to farmers, they may postpone/reduce chemical spraying on their farms. Non-farm income, credit accessibility and asset holding value are also positively significant in terms of chemical quantity. This is because farmers with higher income resources will have a lot of money to spend on farming, so it may increase the input quantity. This is because contract farmers need to grow advanced-quality hybrid seeds provided by firms. These seeds require a greater quantity of fertilisers and pesticides to be used. Hence, seed quantity under CF has a significantly positive influence on the quantity of chemicals used.

3.4 Treatment effects on chemical use

This section addresses the core objective of this study, i.e., the implications of CF on chemical usage for wheat producers. Table 4 reveals the estimated findings of average treatment effects on treated (ATT) for CF adopters and average treatment effects on untreated (ATU) for CF non-adopters. In the same table, base heterogeneity (BH) effects and transitional heterogeneity (TH) effects for adopters and non-adopters are also reported.

The result reveals that CF has a significant impact on chemical usage. The value of ATT is 73 kg/acre or 26.8%, indicating that the farmers who actually adopted CF would have decreased chemical usage by approximately 26.8% if they had not adopted it. So, this is the quantity on which they do not need to invest under NCF. Similarly, in non-adopters case, the value ATU is 102 or

54.2%, indicating that farmers who did not actually adopt CF would have risen chemical quantity by about 54% more if they had adopted it. Thus, the findings point out that farmers who decide to participate in the CF technique instead of moving to the spot market have the tendency to use more chemical inputs, i.e., fertilisers, pesticides, etc. This commercialised technique has severe adverse implications on health as well as environmental sustainability, even though it enhances the gross and net margins for growers.

Table 4. Impacts of contract farming on chemical usage

		Decision Stage		Treatment effect	t-value
		To adopt	Not to adopt		
Chemical used quantity	ATT (CF)	272	199	73 (26.8%)	28.3***
	ATU (NCF)	290	188	102 (54.2%)	92.4***
	Heterogeneity Effect	BH (A) = -18***	BH (N) = 11***	TH = -29	

Source: Authors own work. *Note*: Gross margin is taken in natural logarithm while yield is taken as quintal/acre. The asterisks (***) indicate a 1% level of significance.

The last rows in Table 4 provide information on the effects of heterogeneity in CF on both adopters as well as non-adopters. The base heterogeneity effect is negatively significant for adopters, implying that farm households who adopted CF in the counterfactual case would have utilised more chemicals than the farmers who adopted CF actually. This highlights the importance of heterogeneity sources that make the adopters more efficient than the non-adopters, irrespective of the issue of CF adoption. Similarly, the negative value of the transitional heterogeneity effect indicates that the contracting effect is greater for wheat growers who actually adopted CF relative to those who adopted it in counterfactual cases.

From the above results, it is clear that CF requires a high amount of chemicals for wheat production in the chosen study area. It is opined that unnecessary applications of inorganic chemicals are the root of severe environmental degradation. Similar results are also observed by Zhang et al. (2023). On the contrary, Mishra, Kumar and Dsouza (2021) and Nguyen et al. (2024) found that CF produces higher revenue with reduced quantity of fertilisers. One more study by Ren et al. (2021) stated that CF encourages sustainable agricultural production by promoting organic fertilisers, which, ultimately, protects the environment from the harmful inorganic fertilisers in agriculture. However, the majority of studies reveal that overutilisation of chemicals has detrimental effects on the environment by polluting the groundwater, hardening the soil and surface and harming the air quality as well (Amin and Jilani, 2024; Bijay-Singh and Craswell, 2021; Lenka *et al.*, 2016; Rahman and Zhang, 2018; Savci, 2012) and at same time, it poses a risk to human health (Dhankhar and Kumar, 2023; Sharma and Singhvi, 2017).

4 Conclusion and implications

In order to fulfil the rising demand for food, an intensive form of agriculture with optimum efficiency and productivity is needed for the day. Therefore, the use of farm chemical inputs has been considered necessary in modern agriculture. But, at the same time, a greater quantity of chemical use has many adverse environmental effects, i.e. soil fertility, groundwater contamination, air pollution, etc. When pesticides kill weeds or insects, they can also be hazardous to birds, beneficial insects, and some non-target plants. Similarly, insecticides and herbicides are typically the most fatal type of pesticide, and they can harm animals that are not the planned target. Hence, this study conducted a comparative estimation of chemical usage on wheat farms between CF adopters and non-adopters in Haryana in order to know the effect of CF adoption on the degree of chemical input usage.

The ESR analysis of CF impacts confirms that farmers who decide to produce under CF rather than moving to the open market have a tendency to utilise more chemical inputs. It shows that wheat growers who actually adopted CF would have decreased the quantity of chemical input by 26.8% if they had not adopted it. Correspondingly, non-adopters who did not adopt CF would have utilised 54% more chemicals if they could have adopted it. The significant base heterogeneity effect also implies that farm households who adopt CF in the counterfactual case would have utilised more chemical inputs than the farmers who adopted CF actually. This also highlights the inducement effect of CF on the chemical usage of non-adopters. So, the overall results of this study confirm that CF promotes a greater quantity of chemical inputs to back its high-profit orientation.

The major policy recommendations drawn from this study suggest that, at the time of the contract agreement, the contracting firms should promote organic fertilisers instead of chemical fertilisers. However, care must be taken as CF often prioritises short-term gains over long-term environmental health (Shakeel *et al.*, 2023). Subsequently, firms should try to make minimal use of the acceptable quantity of fertilisers, pesticides, and insecticides for the contracted crops. Environment-friendly fertilisers should be promoted as these can improve the water retention and water-holding capacity of the soil. Moreover, the government should also promote the guidelines for chemical quantity according to crops, seed quality, soil fertility, etc., among the farmers. This may be done through the implementation of agri-environmental policies. Countries across Europe have implemented policies to reduce chemical usage. Many have been successful. China has also managed to turn the tide on fertiliser use, resulting in the trend of fertiliser usage falling after 2015 (Ji *et al.*, 2020). These measures will help to manage the use of fertiliser, improve the nutrient uptake efficiency of plants and decrease environmental pollution. It may reduce the environmental cost of growing the contracted crops and raise farmers' overall welfare.

This study, while comprehensive, has some limitations. First, its geographic focus on Haryana may limit the generalisability of the findings to other regions with different agroecological and socio-economic conditions. Second, the reliance on cross-sectional data from a single agricultural season may not capture variability in chemical input usage across different seasons. Additionally, the study's focus on wheat farming excludes insights into the effects of CF on other crops. Future research could expand the geographic scope, utilise longitudinal data to capture temporal variations and investigate a broader range of crops.

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Online Appendix

Table A1. Validity test for the instrumental variables' selection

	CF Adoption (1/0)		Chemicals used by CF adapters		Chemicals used by CF non-adopters	
	Coef.	S. E.	Coef.	S. E.	Coef.	S. E.
Media	1.728***	0.409	0.021	0.011	0.044	0.141
mbr	0.512**	0.318	0.004	0.031	0.021	0.512
Wald test $\chi2$/F-stat	72.03		0.045		0.036	
Number of obs.	754		323		431	

Source: Authors own work. *Note*: The asterisks (***) and (**) indicate 1% and 5% levels of significance.