ISSN 0971-3441
Online ISSN 0974-0279

January-June 2023
Volume 36
Number 1

Agricultural Economics Research Review

Agricultural Economics Research Association (India)

ISSN 0971-3441
Online ISSN 0974-0279

Agricultural Economics Research Review

Agricultural Economics Research Association (India)
National Agricultural Science Centre Complex
Dev Prakash Shastri Marg, Pusa
New Delhi - 110 012

Agricultural Economics Research Review
Vol. 36 (No.1) 2023

Financial support from:
Indian Council of Agricultural Research (ICAR), New Delhi

Published by:
Dr Anjani Kumar, Secretary, AERA on behalf of Agricultural Economics Research Association (India)

Printed at:
Cambridge Printing Works, B-85, Phase II, Naraina Industrial Area, New Delhi 110 028

ISSN 0971-3441
Online ISSN 0974-0279

Agricultural Economics Research Review

[Journal of Agricultural Economics Research Association (India)]

Volume 36 **Number 1** **January-June 2023**

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Agricultural Economics Research Review 2023, 36 (1), 1-11
DOI: 10.5958/0974-0279.2023.00001.0

Resource conservation technologies for sustainable development of agriculture: A case study in Indian Punjab

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Abstract Punjab has remained pioneer in adopting new farm technologies ever since the advent of paddy and wheat based Green Revolution. However, over time, the emergence of monoculture of paddy and wheat in their respective growing seasons has caused ecological and environmental problems, which needs to be addressed for sustainable development of agriculture. This study has developed optimal crop plans for Punjab, and evolved scenarios considering potential resource conservation technologies options. Results reveal that continuous of existing policies is unlikely to reduce paddy-wheat mono-cropping. The adoption of resource conservation technologies, viz. sowing wheat with Happy Seeder, and direct seeding of paddy and its short-duration have the potential to save water and without any yield or income penalty. Incentivizing farmers for adoption of resource conservation technologies can divert paddy area to crops grown with less water.

Keywords Conservation technologies; Sustainability; Resource use

JEL codes C61, O13, O20

Punjab is situated in the North West of India. It is one of the smallest states with a geographical area of 50,362 sq. Km, i.e., 1.5% of the total geographical area of the country. The development of Punjab agriculture in the past six decades is the result of strategic objectives of external actors. However, these objectives were not motivated by a sustainable development path. The central government policies reinforced the agrarian-oriented path of development. The government policies emphasized cultivation of paddy and wheat, leading to their monoculture (Singh 2012).

The Green Revolution technologies including high-yielding varieties, agrochemicals, and irrigation led to significant increase in agricultural production. To achieve higher productivity, the intensity of input use increased significantly. No denying, this led a significant increase in productivity initially, but at the same time the cost of production increased. Significant increase in fixed costs endangered economic viability of farming, especially on small and marginal farms. In the recent decades, despite the increased use of inputs, the yield of paddy and wheat has started showing signs of fatigue. Not only that, this also started causing degradation to natural resources, including land, water and air.

Agriculture in Punjab has reached a stage where further growth in it is not efficient with available technologies. Rise in cost of cultivation has squeezed the profitability of agriculture. The continuous degradation of natural resources has further added to declining farm profits.

Paddy, though not a traditional crop in Punjab, practically wiped out *kharif* oilseeds and pulses besides and markedly replaced maize and cotton. Being a water-guzzling crop, paddy cultivation has led to over-exploitation of groundwater resources, and also adversely affected soil fertility through nutrient mining. The groundwater table in the state has been declining at an alarming rate. In many areas, excessive exploitation has pushed the groundwater table below the critical depths. Deep tube wells are relied upon in southern region where underground water is saline. Existing cropping pattern, cheap credit, and free supply of electricity are the main factors behind the steep increase in tube wells in the state. In 2010, of the total 138 blocks in the state, 110 blocks were over-exploited (>100% of annual net recharge of water), and only 23 blocks were considered safe. In other words, groundwater in 80% of the geographical area has been over-exploited. Paddy straw management is another challenge. Straw burning has become common in the state causing damages to environment and human health (Dhillon and Sidhu 2018).

To keep the momentum of growth, various expert committees and individuals (Johl 1986, Johl Committee 2002, Alagh Committee 2005, Government of Punjab 2006) have recommended diversifying agriculture away from paddy. This study has examined the potential of diversification under different technological options.

Data and methodology

Data

The study utilizes plot-level data collected under "Comprehensive Scheme for Studying the Cost of Cultivation of Principal Crops" of the Directorate of Economics and Statistics, Ministry of Agriculture & Farmers Welfare, Government of India. Under this scheme, each sample household is surveyed consecutively for three years, and the data used in this paper pertain to the period from 2011-12 to 2013-14. The plot-wise data were collected from the 300 representative households of 30 tehsils in each year in three agro-climatic zones. Farmers were selected following a three-stage stratified sampling technique, with tehsil as first stage, a village or cluster of villages as second stage, and operational holdings within the cluster as third stage. From each cluster, a sample of 10 operational holdings, two each from five size-classes, *viz*. marginal (< 1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-6 ha), and large (> 6 ha), were selected randomly.

Besides, we conducted case studies to work out the cost-return structure of the adopting resource conservation technologies viz; the sowing of wheat with Happy Seeder (HS), Direct Seeding of Paddy (DSP), and sowing of short- duration varieties (SDV) of paddy. The primary data for such case studies were collected from farmers in 2017-18, and coefficients developed were deflated using the consumer Wholesale Price Index (WPI) to the year of cost of cultivation (COC). The paid-out cost, which comprises a part of Cost A_1, was estimated, and the rent paid for leased-in land was added to Cost A_1 to arrive Cost A_2. Net returns from adopting technological interventions were estimated by deducting Cost A_2 + imputed value of family labour (FL)from the gross returns. The results so obtained were used as coefficients in the optimization model.

Net returns over Cost A_2+FL can be defined as the gross return (value of main product + by-product) less (Cost A_2 + imputed value of family labour) at market prices actually paid and received by the farmer or imputed in some cases. Cost A_2 includes all actual expenses in production and rent paid for leased-in land. Some of the components of Cost A_2 are directly retrieved from the unit level data, while other need to be estimated, for example, depreciation on implements and farm buildings and interest on working capital have been estimated. The imputed value of family labour has been calculated as: *Working hours of family labour × Wage rate per hour.*

Optimization of crop model

Mathematical Programming is used for developing optimum crop or land use plans. It is an easy and flexible method for assessing different ways to use limited resources under variable objectives and constraints. In the present study, an attempt has been made to develop different crop planning strategies using *linear programming* (LP). It develops the crop model that increases productivity with minimum input cost under the constraints of available resources like water usage, labour, farm power, working capital fertilizers use, etc., and ultimately provides maximum net benefits. Multi-crop model for two seasons was formulated for maximizing net returns, and minimizing cost and water usage keeping all other available resources (such as cultivable land, human labour, farm power, working capital, groundwater available for irrigation, fertilizer usage) as constraints.

Optimization model

Mathematically, the optimization model can be represented through Equations 1-7 as below:

$$Max\ Z = \sum_{C=1}^{n} (y_{c\ P_c} - C_c)\ A_c$$

$$\sum_t \sum_c A_{tc} \leq NS_t - OA_t$$

$$A_c \geq min_c$$

$$A_c \leq max_c$$

$$\sum_t \sum_c HL_{tc} \leq THL_t$$

$$\sum_c X_c A_c \leq CUX$$

$$A_c \geq 0$$

Objective function: Maximization of net returns

$$\sum_{c=1}^{n} (y_{c\ P_c} - C_c)\ A_c$$

Where, y_c is yield (per ha) of crop c, P_c is the price of the output from crop c, C_c refers to the cost (Rs/ha) incurred in cultivation of crop c, and A_c is the area under crop c. Thus, the objective is to maximize the net returns Z based on the optimum crop plan.

Estimation of constraints

The resources as constraints included in the model are; land (net sown area), human labour, farm power, working capital, groundwater, and fertilizer (N, P & K) usage. The net sown area in the state is taken as the land constraint, while the total number of agricultural workers converted into person-days as human resource availability. In case of farm power, working capital, and fertilizers, their current use is assumed as their availability. However, to ascertain the additional capital requirement for adopting new technologies, a hiring activity of working capital was introduced in the model**.** The details of constraints are given below.

Land: In intensively cultivated and relatively productive states like Punjab, seasonal land availability constraints are unrealistic and should be considered for each month. This can be done by considering separate constraint equations for each month (Equation 2 is a compact form of 12 equations, one for each month (t)), allowing introducing short-duration crops in the cropping system. The area under orchards and perennial crops are excluded from the net sown area.

Crop planning model based on linear programming primarily captures the supply side behavior, more precisely the area response based on net returns and resource constraints, ignoring the demand aspect. Such models tend to overestimate or under-estimate the area allocations for some crops. Consequently, a single crop may cover an infeasible larger area (over-estimation) or null or negligible area (under-estimation). Some major crops may lose relevance in some modeling solutions, and the corresponding area allocations may become insignificant. Then, even though estimates are robust and mathematically proven, such allocations may not be desirable and practically possible from the viewpoint of the country's food security. Similarly, area allocations for some minor crops may be over-estimated, ignoring the demand. Such an area allocation is again undesirable as it may lead to a glut in the market. To avoid such undesirable over-estimation or under-estimation, assigning values to the minimum and maximum area of the selected crops become essential in the model.

Human labour: Assessment of human labour for each month is also required for its optimum use. Therefore, 12 separate constraint equations, one for each month (t), were used in the model to capture monthly human labour usage (HL_{tc}). As a result, it was ensured that the total human labour required for selected crops in a month is less than or equal to the human labour availability (THL_t).

Farm power, working capital, groundwater, and fertilizer usage constraints: Farm power, working capital, and fertilizers usage in Punjab is already on higher side. Current usage (CUX) of these inputs has been taken as total availability. So, usage of these inputs in the optimum plans ($X_c A_c$) should be less than or equal to the current usages.

Water is a scarce natural resource. The groundwater usage should be less than or equal to its current use. These constraints used in Equation (6) of the linear programming (LP) model.

Data for the development of crop plans (CP) for Punjab has been taken from both secondary sources and household survey data from the cost of cultivation (COC). Existing land area allocations under different crops are useful to make a comparison with the optimum crop plan model. The data is available from the Statistical Abstract of Punjab. These data are further useful for defining minimum and maximum area allocation limits for the selected crops. The existing area is based on the three years average of area under the crops. The minimum and maximum area have been determined based on the expert elicitation.

Results and discussion

Optimization of resource use

Under this scenario, the possibilities of resource reallocation were explored with existing set of technologies. The results of the optimization model (Table 1) suggest that the groundwater resources cannot sustain the further increase in gross cropped area. The plan suggest a marginal decrease in area under *rabi* cereals, from 35.3 lakh ha to 33.4 lakh ha. Similarly, the area under *kharif* cereals also decreases from 33.25 lakh ha to 32.80 lakh ha under the existing plan. The model suggests expanding the area under *kharif* pulses at least by 2.5-fold and *kharif* oilseeds mainly groundnut by around 2 lakh ha. The change in area under fodder crops is minimal. The plan can save the water by 18.74% from 35.38 BCM to 28.75 BCM. Following this plan, the net returns over Cost A_2+FL can be increased by 39.35% but mainly from animal husbandry.

Optimal plan with intervention 1 (Happy Seeder)

Farmers burn paddy straw as the window after paddy harvest is 2-3 weeks for sowing of wheat. This is insufficient for pre-sowing operations. The requirement

Table 1 Existing area vis-à-vis area under existing optimal plan, Punjab

(Area: 000'ha)

Crop category	Crops	Existing area	% of GCA	Area under existing optimal plan	% of GCA
Rabi cereals	Wheat	3519.33	43.17	3343.64	42.22
	Barley	14.00	0.17	11.20	0.14
	Total	3533.33	43.34	3354.84	42.36
Kharif cereals	Paddy	2787.67	34.2	2311.84	29.19
	Maize	141.00	1.73	107.00	1.35
	Basmati	396.67	4.87	862.00	10.89
	Total	3325.34	40.79	3280.84	41.43
Kharif pulses		17.75	0.22	47.24	0.6
Rabi pulses		4.07	0.05	2.40	0.03
*Rab*i oilseeds		48.96	0.6	18.40	0.23
Kharif oilseeds	Groundnut	2.60	0.03	192.40	2.43
Vegetables	Potato	76.53	0.94	105.50	1.33
	Peas	18.93	0.23	10.00	0.13
Cash crops	Cotton-BT	492.67	6.04	300.00	3.79
	Sugarcane	70.33	0.86	46.00	0.58
Kharif fodder		263.52	3.23	3.23	3.33
Rabi fodder		297.96	3.65	3.66	3.76
Net sown area (NSA)		4130.00	-	4130.00	-
Gross cropped area (GCA)		8152.00	100	7919.10	100.00
Cropping intensity (CI) (%)		197.38	-	191.74	-
Livestock number (in thousands)	Crossbred cows	1823.8	-	1823.80	-
	Buffaloes	4626.03	-	9117.66	-
Net returns over A2+FL (Rs billion)		432.00	-	602.00	-

of dry fodder is met from wheat straw. Besides, fodder crops are grown in a significant area. The equipment and the process of cutting and ploughing back or collecting and transporting straw involve huge cost. A high content of silicon dioxide (SiO_2) in straw resists its decomposition when incorporated/retained in the soil. Incorporation of straw in the soil is physically difficult and requires more tillage operations to sow wheat which casues an increase in sowing cost. Then there is fear of the possibility of carrying forward infections/diseases with straw if ploughed back into the soil. In addition, an acute shortage of labour for collecting and storage of paddy straw also leads towards straw burning (Government of Punjab 2014).

There is also the availability of alternate technologies to stop farmers from burning residues and which doesn't even increase field preparation costs or alter crop yields like Happy Seeder. Happy Seeder cuts and lifts paddy straw, sows' wheat into the bare soil, and deposit the straw over the sown area as mulch. This allows farmers to sow wheat immediately after their paddy harvest without the need to burn any paddy residue (Gupta 2012).

Table 2 compares the current area allocation with that of the optimized plan with the intervention being wheat sown with Happy Seeder. This plan suggests decreasing area under wheat by 5.19% as well as the total area under *rabi* cereals by 5.24%. Accordingly, the area

Table 2 Existing area vis-à-vis area under optimal plan with intervention 1(Happy Seeder), Punjab

(Area: 000'ha)

Crop category	Crops	Existing area	% of GCA	Area under optimal plan with intervention 1 (Happy Seeder)	% of GCA
Rabi cereals	Wheat	3519.33	43.17	2744.23	34.65
	Wheat (HS)*	-	-	592.50	7.48
	Wheat total	3519.33	43.17	3336.73	42.13
	Barley	14.00	0.17	11.20	0.14
	Total	3533.33	43.34	3347.93	42.27
Kharif cereals	Paddy	2787.67	34.2	2299.93	29.04
	Maize	141.00	1.73	107.00	1.35
	Basmati	396.67	4.87	862.00	10.89
	Total	3325.34	40.79	3268.93	41.28
Kharif pulses		17.75	0.22	59.14	0.75
Rabi pulses		4.07	0.05	2.40	0.03
*Rab*i oilseeds		48.96	0.6	18.40	0.23
Kharif oilseeds		2.60	0.03	192.40	2.43
Vegetables	Potato	76.53	0.94	112.40	1.42
	Peas	18.93	0.23	10.00	0.13
Cash crops	Cotton-BT	492.67	6.04	300.00	3.79
	Sugarcane	70.33	0.86	46.00	0.58
Kharif fodder		263.52	3.23	263.52	3.33
Rabi fodder		297.96	3.65	297.96	3.76
Net sown area (NSA)		4130.00	-	4130.00	-
Gross cropped area (GCA)		8152.00	100	7919.10	100.00
Cropping intensity (CI) (%)		197.38	-	191.74	-
Livestock number (in thousands)	Crossbred cows	1823.80	-	1823.80	-
	Buffaloes	4626.03	-	9204.10	-
Net returns over A2+FL(Rs billion)		432.00	-	608.00	-

*Happy Seeder

under wheat should be reduced from 35.19 lakh ha to 33.36 lakh ha, further dividing it into two categories, i.e., normal wheat sowing (82.24 %) and wheat sown with Happy Seeder (17.76 %). The plan has suggested almost doubling the gross cropped area under basmati paddy and decreasing the area under non-basmati paddy by about 17%. Again, the areas under *rabi* pulses and oilseeds need to be decreased to 59% and 62%, respectively. Among cash crops, area under Bt cotton and sugarcane should be decreased. Following this, the gross cropped area (GCA) would fall to 79.19 lakh ha from the current level of 81.52 lakh ha. The total cropping intensity is decreased to 191.74%. The results show a saving of 18.88% in water and an increase in net returns by 40.74%.

Optimal plan with intervention 2 (Happy Seeder+ DSP)

Direct seeded paddy refers to the process of growing paddy crop from seeds sown in the field rather than by transplanting paddy seedlings from the nursery. To save water, reduce labour requirements, and mitigate greenhouse gas emissions, Direct Seeded Paddy (DSP) is a feasible alternative to conventional puddle transplanted paddy. Mechanization of farming practices can overcome the crisis and help in drudgery reduction (Din *et al*., 2012). Exploring ways to produce more paddy with less water is essential for food security and sustaining environmental health (Tuong and Bouman 2003).

Water application in paddy production, therefore, needs to be decreased by increasing water-use efficiency through reduced losses caused by seepage, percolation and evaporation. The DSP has got potential to improve the efficiency of water use. Faced with an imminent threat of plummeting water table, the government of Punjab has been prompting DSP.

In the scenario of fast-paced depletion of groundwater in Punjab and intensive cultivation of paddy involving a high amount of water and labour use, so there is an urgent need to shift from the traditional transplanting method of paddy cultivation to DSP (Bandumula *et al* 2018).

A comparison of existing area under different crops and that under the optimal plan with interventions being wheat sown with Happy Seeder and Direct Seeded Paddy is presented in Table 3. The results show that the total cropped area under wheat and paddy should be decreased drastically by 24.71 and 36.68%,

Table 3 Existing area vis-à-vis area under optimal plan with intervention 2 (Happy Seeder and DSR), Punjab

(Area: 000'ha)

Crop category	Crops	Existing area	% of GCA	Area under optimal plan with intervention 2 (HS& DSR)	% of GCA
Rabi cereals	Wheat	3519.33	43.17	2057.00	28.45
	Wheat (HS)*	-	-	592.50	8.19
	Wheat total	3519.33	43.17	2649.50	36.64
	Barley	14.00	0.17	11.20	0.15
	Total	3533.33	43.34	2660.07	36.79
Kharif cereals	Paddy	2787.67	34.20	1600.00	22.13
	Paddy DSP**	-	-	165.00	2.28
	Basmati	396.67	4.87	862.00	11.92
	Paddy basmati total	3184.34	38.07	2627.00	36.33
	Maize	141.00	1.73	107.00	1.48
	Total	3325.34	40.79	2734.00	37.81
Kharif pulses		17.75	0.22	83.47	1.15
Rabi pulses		4.07	0.05	2.40	0.03
*Rab*i oilseeds		48.96	0.60	18.40	0.25
Kharif oilseeds		2.60	0.03	15.33	0.21

contd...

Vegetables	Potato	76.53	0.94	111.96	1.55
	Peas	18.93	0.23	10.00	0.14
Cash crops	Cotton-BT	492.67	6.04	300.00	4.15
	Sugarcane	70.33	0.86	733.66	10.15
Kharif fodder		263.52	3.23	263.52	3.64
Rabi fodder		297.96	3.65	297.96	4.12
Net sown area (NSA)		4130.00	-	4130.00	-
Gross cropped area (GCA)		8152.00	100	7231.42	100.00
Cropping intensity (CI) (%)		197.38	-	175.09	-
Livestock number (in thousands)	Crossbred cows	1823.80	-	1823.80	-
	Buffaloes	4626.03	-	12727.30	-
Net returns over A2+FL (Rs billion)		432.00	-	659.00	-

*Happy seeder ** Direct Seeded Paddy

respectively. The area under sugarcane should be increased by more than 10 times while that under cotton should be decreased by 39.1%. Following this, the GCA decline by 11.3%, water use is reduced by 10.18%, and net returns will increase by 52.55%.

Optimal plan with intervention 3 (Happy Seeder + Short Duration Varieties)

Two types of varieties of paddy are grown in the state - long duration and short duration. Long-duration varieties like Pusa 44, are sown in some districts adjoining Haryana. This variety has not been recommended by the PAU. PR 121 and PR 126 are the short-duration varieties sown by the farmers and recommended by PAU. These varieties are high-yielding and mature 20-37 days earlier than Pusa 44. Growing of short-duration varieties facilitate cultivation of three crops a year (Manan *et al.* 2018).

Punjab farmers deserve appreciation for adopting short-duration paddy varieties, which in 2017 occupied about 69% of parmal paddy area. On account of short duration and low biomass, these varieties save irrigation water and lower cost on pesticides (Dhillon and Bains 2018).

Table 4 shows the current areas under different crop categories with those under the optimal plan with the

Table 4 Existing area vis-à-vis area under optimal plan with intervention 4 (Happy Seeder and Short duration paddy varieties), Punjab

(Area: 000'ha)

Crop category	Crops	Existing area	% of GCA (HS SDV)	Area under optimal plan with intervention 3	% of GCA
Rabi cereals	Wheat	3519.33	43.17	2796.64	35.28
	Wheat (HS)*	-	-	592.50	7.47
	Wheat total	3519.33	43.17	3389.14	42.75
	Barley	14.00	0.17	11.20	0.14
	Total	3533.33	43.34	3400.34	42.89
Kharif cereals	Paddy	2787.67	34.20	1097.87	13.85
	Paddy PR121	-	-	625.00	7.88
	Paddy PR126	-	-	625.00	7.88
	Basmati	396.67	4.87	862.00	10.87
	Paddy total	3184.34	39.07	3209.87	40.48
	Maize	141.00	1.73	171.95	2.17
	Total	3325.34	40.79	3381.82	42.65

Contd...

Kharif pulses		17.75	0.22	15.65	0.20
Rabi pulses		4.07	0.05	2.40	0.03
*Rab*i oilseeds		48.96	0.60	26.55	0.34
Kharif oilseeds		2.60	0.03	123.01	1.55
Vegetables	Potato	76.53	0.94	60.00	0.76
	Peas	18.93	0.23	10.00	0.13
Cash crops	Cotton-BT	492.67	6.04	300.00	3.78
	Sugarcane	70.33	0.86	46.00	0.58
Kharif fodder		263.52	3.23	263.52	3.32
Rabi fodder		297.96	3.65	297.96	3.76
Net sown area (NSA)		4130.00	-	4130.00	-
Gross cropped area (GCA)		8152.00	100	7927.25	100.00
Cropping intensity (CI) (%)		197.38	-	191.94	-
Livestock number (in thousands)	Crossbred cows	1823.80	-	1823.80	-
	Buffaloes	4626.03	-	9477.55	-
Net returns over A2+FL (Rs billion)		432.00	-	620.00	-

*Happy Seeder; SDV stands for short duration varieties

intervention being wheat sown with Happy Seeder and Short Duration Varieties of paddy. Under this plan, the total area under wheat decreases from 35.19 lakh ha to 33.89 lakh ha, of which 5.92 lakh ha to be sown with Happy Seeder. The total area under paddy is decreased from 27.87 lakh ha to 23.47 lakh ha, whereas under basmati paddy it is increased from 3.96 lakh ha to 8.62 lakh ha. This will lead to an increase in the area under the *kharif* cereals from 33.25 lakh ha to 33.82 lakh ha. This plan leads to 21.65% water saving and 43.52% higher net returns.

Optimal plan with all interventions: A final comparison has been made in Table 5 of the current area under the various crops and the area allocated under the optimal plan with all the interventions taken together. There is a decline in total area under wheat from 35.19 lakh ha to 33.89 lakh ha under the new

Table 5 Existing area vis-à-vis area under optimal plan with all interventions (Happy seeder, DSR, SDV), Punjab

(Area: 000'ha)

Crop category	Crops	Existing area	% of GCA	Area under optimal plan with all interventions	% of GCA
Rabi cereals	Wheat	3519.33	43.17	2796.64	35.28
	Wheat (HS)*	-	-	592.50	7.47
	Wheat total	3519.33	43.17	3389.14	42.75
	Barley	14.00	0.17	11.20	0.14
	Total	3533.33	43.34	3400.34	42.89
Kharif cereals	Paddy	2787.67	34.20	910.19	11.48
	Paddy DSP**	-	-	165.00	2.08
	Paddy PR121	-	-	625.00	7.88
	Paddy PR126	-	-	625.00	7.88
	Basmati	396.67	4.87	862.00	10.87
	Paddy total	3184.34	39.07	3187.19	40.19
	Maize	141.00	1.73	316.23	3.99
	Total	3325.34	40.79	3503.42	44.18

Contd...

Kharif pulses		17.75	0.22	15.65	0.20
Rabi pulses		4.07	0.05	2.40	0.03
*Rab*i oilseeds		48.96	0.60	26.55	0.34
Kharif oilseeds		2.60	0.03	1.40	
Vegetables	Potato	76.53	0.94	60.00	0.76
	Peas	18.93	0.23	10.00	0.13
Cash crops	Cotton-BT	492.67	6.04	300.00	3.78
	Sugarcane	70.33	0.86	46.00	0.58
Kharif fodder		263.52	3.23	263.52	3.32
Rabi fodder		297.96	3.65	297.96	3.76
Net sown area (NSA)		4130.00	-	4130.00	-
Gross cropped area (GCA)		8152.00	100.00	7927.25	100.00
Cropping intensity (CI) (%)		197.38	-	191.94	-
Livestock number (in thousands)	Crossbred cows	1823.80	-	1823.80	-
	Buffaloes	4626.03	-	9711.28	-
Net returns over A2+FL (Rs billion)		432.00	-	624.00	-

*Happy seeder ** Direct Seeded Paddy

optimal plan. The area under *rabi* cereals is decreased from 35.33 lakh ha to 34 lakh ha. The total area of paddy under the optimal plan has been sub-categorized into the area under paddy DSP, PR 121 and PR 126, which accounts for 2.08, 7.88 and 7.88 per cent of GCA under the new plan. The total area under paddy is decreased to 23.25 lakh ha from 27.87 lakh ha. Among the cash crops, the area under Bt cotton as well as sugarcane is decreased. This will result in approximately 21.34% saving in water, and 44.44 higher net returns.

Resource use under different optimal plans: The resource use under different plans is shown in Table 6. There is an increase in the annual labour hours and a decrease in water use under all the plans as compared to the existing value. Farm power and fertilizer use per hectare decline, except potassic fertliers.

Percent changes in resource use under the optimal plans are presented in Table 7. The annual labour hours and net returns increase in all the plans. The water use, farm power and fertilizer use decline significantly.

Table 6 Resource Use under different optimum plans in Punjab

Resources		Existing	Existing optimized plan	Optimal plan with intervention_1	Optimal plan with intervention_2	Optimal plan with intervention_3	Optimal plan with all interventions
Labour (Million hours/year)		4611.61	5948.80	5962.94	7473.98	5978.06	6013.03
Water (BCM)		35.38	28.75	28.70	31.78	27.72	27.83
Farm power (Million HP hours)		14191.11	13714.64	13692.64	12619.41	13802.05	13802.05
	N	1332.44	1267.49	1266.67	1222.65	1237.90	1237.78
Fertilizer (Million kg)	P	391.00	376.29	376.46	345.13	356.93	359.11
	K	26.59	28.92	28.92	28.92	21.62	22.18

Table 7 Percentage change over existing plan under various interventions in Punjab

Resources		Percentage increase or decrease over existing plan				
		Existing optimised plan	Optimal plan with intervention 1 (HS)	Optimal plan with intervention 2 (HS DSR)	Optimal plan with intervention 3 (HS SDV)	Optimal plan with all interventions
Labour		29.00	29.30	62.07	29.63	30.39
Water		-18.74	-18.88	-10.18	-21.65	-21.34
Farm power		-3.36	-3.51	-11.08	-2.74	-2.74
Fertilizer	N	-4.87	-4.94	-8.24	-7.10	-7.10
	P	-3.76	-3.72	-11.73	-8.71	-8.16
	K	8.74	8.74	8.74	-18.68	-16.58
Net Returns over Cost A_2+FL		39.35	40.74	52.55	43.52	44.44

Conclusions

- The labour usage in the existing optimized plan and with the introduction of various resource conservation technologies such as Happy Seeder for wheat sowing, direct-seeding of paddy and short duration paddy varieties recommend higher labour requirement.
- The optimized plan for Punjab also suggest a considerable decline in farm power usage which is quite good in terms of energy-saving as well as judicious use of resources such as irrigation water, diesel, etc.
- The optimized plan along with the introduction of various interventions reveal saving of nitrogenous and phosphatic fertilizers, which are significantly higher than the recommended levels. On the other hand, most of the optimized plans with technological interventions recommend higher use of potash.
- The optimized plan also recommend increasing the area under basmati paddy, potato, peas, moong and sugarcane. But the production of these crops is demand-driven and it should be seen in the context of limited export potential of basmati paddy to Gulf Countries and the European Union (EU) as well as sluggish domestic demand. Potato price received by farmers depends on production in leading potato states. Area under peas is confined to Amritsar and Hoshiarpur districts, and an increase in area under this crop would have a significant impact on prices received by the farmers. However, as suggested by the optimized plan, the area under moong can be increased.
- The optimized plan under various interventions recommends bringing more area under wheat sown with Happy Seeder, short duration paddy varieties and Direct Seeded Paddy.
- The optimized plan also reveal groundwater saving with the introduction of resource-saving technologies, and an increase in net returns.
- Optimized plans suggest increasing the number of buffaloes, and keeping crossbred cows at the same level.

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Received 5 December 2022 Accepted 27 April 2023

Agricultural Economics Research Review 2023, 36 (1), 13-20
DOI: 10.5958/0974-0279.2023.00002.2

Trade-off between greenhouse gas emission tax and paddy production

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Abstract Rice cultivation is an important contributor to the greenhouse gas emissions. The rice cultivators, however, do not pay for the greenhouse gas emissions. This paper estimates the cost of greenhouse gas emissions from the perspective of imposing an emission tax, and consequently its impact on rice production. The findings show that imposing an emission tax causes a reduction in rice production and leads to an increase in its price, given the critical role of rice in India, in terms of both production and consumption. More importantly, it will adversely affect the nation's food security. Thus, there is a need for promoting adaptation and mitigation technologies and practices to reduce the greenhouse gas emissions.

Keywords Greenhouse gases, emission tax, rice, emission

JEL codes D01, Q10, Q51, Q56, Q58

Sustainability is the ability to exist relentlessly. There is no doubt that 'Air' the elementary foundation of our existence will exist as long as the earth does, but what about its quality? Has the quality sustained over the years? No! absolutely not! Today air pollution has emerged as a global public health problem causing seven million premature deaths every year. The Organization for Economic Co-operation and Development (OECD) has projected that air pollution will be the top environmental cause of mortality by 2050. The air quality and the climate change are steadfastly related and this link has led to changes in the global environment leading to global warming. Global warming has increased from 37% in 2016 to 45% in 2017 due to increase in the concentration of greenhouse gases (GHGs), namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and Chlorofluorocarbons (CFCs) in the atmosphere. These trap the outgoing infrared radiations from the earth's surface and thus raise its temperature. In India, pre-industrial level of carbon dioxide was about 280 parts per million (ppm) by volume, and the current level is greater than 380 ppm. In its Special Report on Emission Scenarios (SRES) the Intergovernmental Panel on Climate Change (IPCC) has predicted carbon dioxide concentration in the range of 490 to 1260 ppm by the end of 21^{st} century.

GHGs and Indian agriculture

India is an agriculture based economy and contributes 14 % to the emission of non-carbon dioxide GHGs, viz., methane and nitrous oxide. The enteric fermentation in animal production, agricultural soil activities, and anaerobic rice cultivation are major sources of GHG emissions, accounting for 58.19%, 20.78% and 18.29% of the total agricultural emissions, respectively (Table 1).

India is the second largest producer of rice in the world with 43 million ha area, contributing 22% to the global rice production and contributing 3.3 million tons of methane and 1.42 million tons of nitrous oxide production. The global warming potential of methane emission from rice is estimated four-times more compared to other cultivated cereals (Linquist et al. 2012).

Table 1 The subsector-wise Green House Gas emissions under Agriculture sector

S. No.	Sub-sectors	Emission (million tons CO_2-eq.)	Contributions of the different subsectors to total agricultural emissions (%)
1	Enteric fermentation in livestock	227.034	58.19
2	Manure management	2.768	0.71
3	Rice cultivation	71.368	18.29
4	Agricultural soils	81.081	20.78
5	Field burning of crop residue	7.915	2.03
	Total	390.165	100.00

Source MOEF&CC (2015)

Pollution charges, emission limits, and trading are major market-based instruments for reducing industrial carbon emissions. Emission charges are designed based on *'the polluter pays principle'*, that is, payment must be made by a polluter per unit of pollutant emitted. Emission trading involves buying and selling of the permits and credits. It works by setting quantitative limits on the emissions. Similarly, pollution charges can be applied to agriculture. Emission trading can be implemented by the government by allotting transferable emission permits to farmers to reduce methane and nitrous oxide emissions. Supply and demand for emission permits determines the price of carbon credits. These economic instruments can also incentivize farmers to adopt mitigation technologies. These also help farmers to make choices of crops.

Economic approach to internalize cost of emission

There exist a number of alternative practices to reduce GHGs emissions from agriculture. Their adoption is voluntary, guided by their costs of implementation relative to the existing practices, and likely benefits; hence such practices may fail to address the problem of GHGs.

The economic problem is that the emitters of greenhouse gases (GHGs) do not face the full cost implications of their actions. There are costs that emitters do face, e.g., the costs of the fuel, but there are other costs that are not necessarily included in the prices of goods and services. These are called the external costs. These are "external" because the emitters do not bear these. The external costs affect social welfare. These external costs can be estimated and converted into a common (monetary) unit. The argument for this is that the external costs can then be added to the private costs. In doing so, the emitters face the full (social) costs of their actions and therefore can consider in their decisions and actions.

There are several studies regarding the emission taxes and emission trading in the energy sector, but are extremely limited in the agricultural sector. This is the research gap this study tries to fill. In this study, we have empirically demonstrated 'how emission taxes can impact rice production'.

Methodology

Valuation of GHGs

To assess the impact of emission taxes on rice production and prices, methane and nitrous oxide emissions are valued to internalize the costs of their emission from rice fields. The internalization of emission cost is done by taxing the volume of methane and nitrous oxide emission. Methane and nitrous oxide emissions are valued using the concepts of global warming potential and price of carbon dioxide equivalent. The methane and nitrous oxide emissions estimates used for this analysis are the average methane and nitrous oxide emissions from paddy, that is, 110 kg/ha and 33 kg/ha respectively (Muhammad et al. 2018). Due to their different warming properties and lifetimes, GHGs vary in their radiating intensity. Methane and nitrous oxide emissions are converted into their carbon dioxide-equivalent applying the concept of global warming potential (GWP). The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its GWP for the given time horizon (IPCC 2007).

The CO_2-eq emission is valued at the existing carbon price. The carbon price is the price that has to be paid (to the public authority as a tax, or on emission permit exchange) for emission of one ton of CO_2 into the atmosphere. The price of carbon traded in the market and also the shadow price of carbon are used for valuing methane emissions (in CO_2-eq).

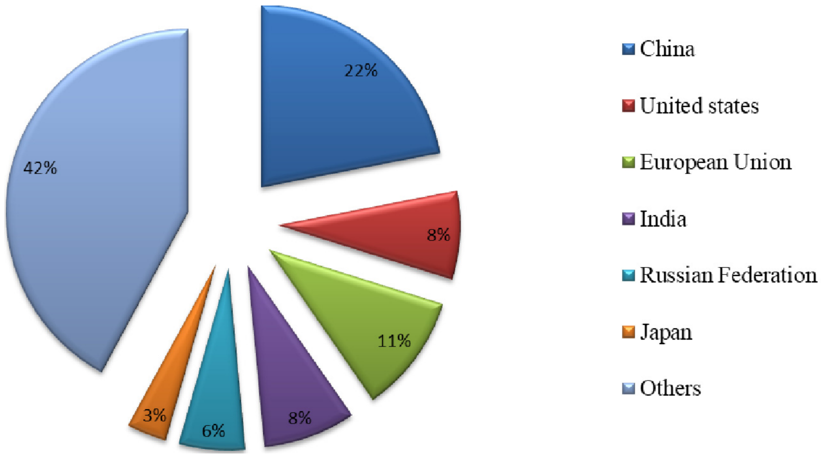

Figure 1 Countries contributing to global greenhouse gases emissions 2017-18
Source Jos G.J. Olivier and Jeroen A.H.W. Peters, 2018.

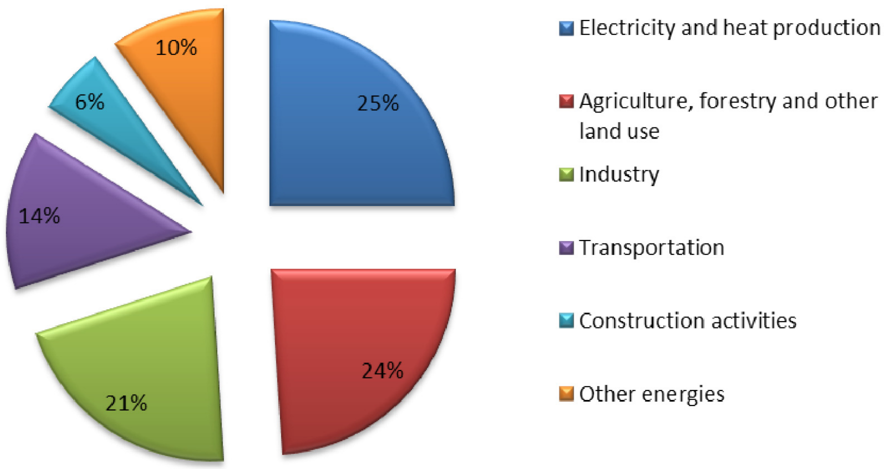

Figure 2 Various economic activities contributing to global greenhouse gases emissions 2017-18
Source Jos G.J. Olivier and Jeroen A.H.W. Peters, 2018.

The average market price of carbon in 2018 was Rs 708.84/ t or approximately US$ 10/t (Manjyot 2018) and it has been considered as the market price of carbon (MPC). The shadow price of carbon (SPC) in 2018 was Rs 2125.2/t or approximately US$ 30/t. The price is determined by the demand and supply of carbon credits. We consider MPC and SPC as proxy for emission tax.

Data on area and production of paddy were obtained from indiastat.com for 2018. The data on cost of cultivation of rice at the national level were obtained from the report of the Commission on Agricultural Costs and Prices. The cost of production was used to calculate the supply shift parameter. Demand elasticity (-0.481) was taken from Chand (1999) and the supply elasticity (0.374) from Mittal (2007). Price of rice was obtained from the World Bank and Ecofys (State and Trends of Carbon Pricing, 2018) as Rs. 29507.89/t. Methane and nitrous oxide emissions from rice fields were assigned a monetary value to consider it as cost of cultivation to serve as the determinant of shift in rice production.

Supply effects

The effect of emission tax on rice production was analysed using the concepts of iso-elastic supply functions and shift parameter. The Tax_{spc} (shadow price) and Tax_{mpc} (market price) were used as the hypothetical taxes on methane and nitrous oxide emissions from rice fields. Internalization of these external costs forms the basis of analysis as these increase the production cost and tends to bring about a shift in the supply curve. This, in turn, causes corresponding changes in the price and demand for rice.

The iso-elastic supply function incorporating the shift parameter was used to examine the shift in rice production due to the internalization of emission costs (Schwarz *et al.,* 2007).

$$Qs = c\,(1-f)Ps\hat{}Es \quad (1)$$

Where, in equation (1) *Qs* is the new level of rice production after the inclusion of the cost of methane and nitrous oxide emissions through the shift parameter *f*, P_s is the supply price of rice in Rs / t, E*s* is the supply elasticity of rice, and *c* is the supply constant calculated as:

$$c = \frac{Q}{Ps^{Es}} \quad (2)$$

Where, in equation (2) *Q* is the rice production (in million tons) without emission tax.

The shift parameter, *f*, is the percent change in the cost of cultivation of rice when the tax on methane and nitrous oxide emissions are included separately in the production costs, i.e.,

$$f = \frac{(C_0 - C_1)}{C_1} \quad (3)$$

Where, in equation (3) C_1 is the cost of cultivation (in Rs/ha) inclusive of the emissions tax, and C_o is the cost of cultivation (in Rs/ha) without the emission tax.

A hypothetical shift in the supply curve due to the tax on nitrous oxide emission is shown in figure 3. The supply curve shifts from S_0 to S_1, where, S_0 is the original supply curve and S_1 is the new supply curve after external costs of methane and nitrous oxide emissions are considered in the cost of production.

Demand and price effects

The shift in supply curve brings about corresponding changes in the price and demand for rice. With this assumption of market equilibrium, the new supply curve also shifts the point of market equilibrium from E_0 to E_1 to adjust to the changes in supply (Fig. 3). At

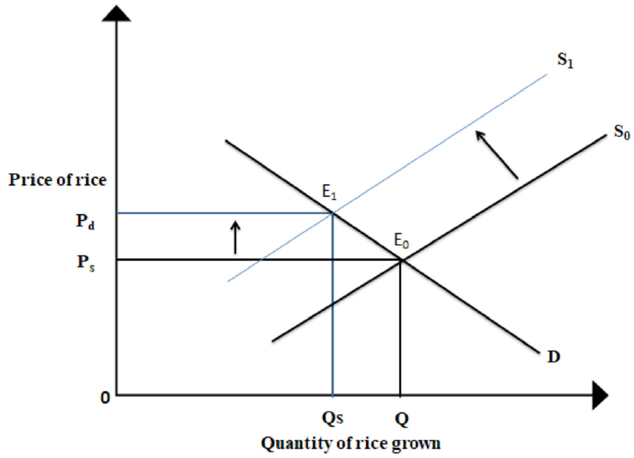

Figure 3 Hypothetical shift in the supply curve

the new equilibrium point E_1, the quantity of rice demanded is equal to the quantity of rice supplied (Q_s), consequently changing the equilibrium price to P_d.

In order to compute the new equilibrium price in the changed situation we follow Schwarz et al. (2007).

$$E_S = \frac{Qs - Q}{Pd - Ps} \times \frac{Ps}{Q} \quad (4)$$

Where, in equation (4) E_s is the supply elasticity of rice, Q_s is the new level of rice production; Q is the current level of rice production, P_s is the supply price, P_d is the demand price in new market equilibrium. The expression was solved for P_d (Equation 5) in order to obtain the new equilibrium market price at which rice will be demanded when methane and nitrous oxide emissions are taxed.

$$Pd = \left[\frac{Qs - Q}{E_S} \times \frac{Ps}{Q}\right] + Ps \quad (5)$$

Implementing emission tax

The emission taxes cannot be applied randomly to all the states cultivating rice. Hence, we group the states based on their methane and nitrous oxide emission levels i.e., emission values (EV) as ‘extremely alarming’, ‘highly alarming’, ‘alarming’ and ‘moderately alarming’.

Data from multiple sources were used to enumerate, measure, and depict the emission scenarios from agriculture. All the livestock-related data were collected from the 20th livestock census 2019), and data related to area under cultivation, area under rice, use of synthetic fertilizers and crop residue burning were collected from Indiastat.com. To calculate and express the existing status of GHG emissions at state level, an Emission Index (EI) has been developed (Table 4).

To construct EI for each state, the contribution of each subsector of agriculture to GHG emissions was considered. The share of each subsector in the agricultural emissions inventory was calculated and expressed as the Emission Value (EV), namely, EV-L (livestock), EV-N (nitrogen/synthetic fertilizer use), EV-R (rice cultivation), and EV-C (crop residue and burning). All the EVs of a state were added to obtain the EI of the state (Equation 6).

$$EI = \Sigma\,(EV\text{-}L+EV\text{-}N+EV\text{-}R+EV\text{-}C) \qquad (6)$$

The shares of different subsectors to the total agricultural emissions were obtained from MOEF&CC (2015). The enteric fermentation and manure management together account for 58.19% of the total agricultural emissions, followed by nitrogen (20.78%, agricultural soils), rice cultivation (18.29%), and crop residue burning (2.03%) (Table 1). The contribution of each subsector was divided by 100 to obtain an Emission-Conversion Value (ECV).

$$EV-L = \frac{\text{Livestock population in the state / ha}}{\text{Maximum livestock population / ha}} \times (ECV-L) \qquad (7)$$

$$EV-N = \frac{\text{Consumption of nitrogenous fertilizer in the state / ha}}{\text{Maximum consumption of nitrogenous fertilizers / ha}} \times (ECV-N) \qquad (8)$$

$$EV-R = \frac{\text{Area under rice cultivation of a state / ha}}{\text{Maximum area under rice cultivation / ha}} \times (ECV-R) \qquad (9)$$

$$EV-C = \frac{\text{Crop residue burning of a state / ha}}{\text{Maximum residue burnt / ha}} \times (ECV-L) \qquad (10)$$

Emission index for each state was calculated using the emission values. States were categorized as, “extremely alarming”, “highly alarming”, “alarming” and “moderate” based on the mean and standard deviation.

Results and discussion

Results indicate a total emission tax of Rs.8916 and Rs. 26673 per hectare at market price (MPC) and shadow price (SPC) of carbon, respectively (Table 2). MPC includes Rs. 1950 as methane emission tax and Rs.6966 as and nitrous oxide emission tax. SPC includes Rs. 5848 and Rs. 20825 for methane and nitrous oxide emission taxes, respectively. SPC based tax is higher as it includes the damage caused by the emissions to the environment. SPC accounts for the social cost, but in practice emission taxes are calculated at market price of carbon.

Table 2 Valuing emission / emission tax

Particulars	Tax at market price of carbon (Rs/ha)
Tax CH_4	1950.00
Tax N_2O	6966.00
Total emission tax	8916.00
	Tax at shadow prices of carbon (Rs/ha)
Tax CH_4	5848.00
Tax N_2O	20825.00
Total emission tax	26673.00

Source Authors Calculations

Effect of emission taxes on rice production

In 2018, India produced 112.91 million tons of rice, which with the imposition of methane tax could have reduced to 109.19 million tons, and with total tax ((CH_4 + N_2O) to 95.97 million tons. The reduction could have more in case of imposition of emission taxes based on SPC (Table 3).

The supply shift brings about changes in demand and price of rice. As a result of supply shift, the new equilibrium price could have been 31526 Rs/ t, and 38710 Rs/ t respectively on the imposition of methane tax and total tax (CH_4 + N_2O) (Table 3). The prices would have been more in case of SPC based taxes. Thus, there is a clear reduction in the demand and a surge in price of rice if cost of emissions are considered, and there is a rent transfer from consumer to producer due to downward shift in supply.

GHG emissions vary across states depending on the intensity of GHG emitting activities. The emission index for a state are calculated summing up the emission values of all the agriculture related activities (Table 4). Punjab, West Bengal and Tripura have higher emission index values, while Rajasthan, Madhya Pradesh and Sikkim have the lowest emission index values.

Table 3 Change in Rice production and prices at different tax levels

	Tax amount (Rs/ha)	Production shift million tons	Per cent decrease in production	Price shift (Rs/ton)	Price shift (Rs/kg)	Percent increase in price
			Tax at Market Price of Carbon (Rs/ha)			
Tax CH4	1950	109.19	3.29 %	31526	31.52	6.84 %
Total tax	8916	95.97	15 %	38710	38.71	31.1 9 %
			Tax at Shadow Prices of Carbon (Rs/ha)			
Tax CH4	5848	101.75	9.88 %	35569	35.56	20.54 %
Total tax	26673	73.35	35.04 %	50646	50.65	71.64 %

Source Authors Calculations

Table 4 State wise emission index of for 2018

States	EV-Livestock (L)	EV-Rice field (R)	EV- N fertilizers (N)	EV - Residue burning (C)	Emission index
Andhra Pradesh	0.4	0.05	0.16	0.80	1.41
Arunachal Pradesh	0.35	0.00	0.04	0.53	0.92
Assam	0.34	0.06	0.03	0.67	1.11
Bihar	0.17	0.10	0.15	0.69	1.11
Chhattisgarh	0.17	0.12	0.08	0.36	0.73
Goa	0.07	0.00	0.03	0.92	1.02
Gujarat	0.08	0.03	0.10	0.66	0.86
Haryana	0.31	0.05	0.16	1.39	1.90
Himachal Pradesh	0.22	0.00	0.04	0.32	0.59
Jammu & Kashmir	0.48	0.01	0.05	0.45	0.98
Jharkhand	0.52	0.06	0.03	1.08	1.69
Karnataka	0.17	0.02	0.12	0.40	0.71
Kerala	0.27	0.01	0.03	0.19	0.49
Madhya Pradesh	0.07	0.06	0.06	0.18	0.37
Maharashtra	0.13	0.05	0.09	0.45	0.71
Manipur	0.18	0.00	0.03	0.41	0.62
Meghalaya	0.39	0.00	0.04	0.35	0.78
Mizoram	0.34	0.00	0.02	0.22	0.58
Nagaland	0.17	0.01	0.03	0.39	0.60
Odisha	0.19	0.11	0.04	0.62	0.97
Punjab	0.12	0.10	0.17	2.29	2.68
Rajasthan	0.08	0.01	0.04	0.17	0.30
Sikkim	0.2	0.00	0.00	0.19	0.39
Tamil Nadu	0.58	0.05	0.12	0.79	1.54
Tripura	0.5	0.01	0.03	1.76	2.30
Uttar Pradesh	0.11	0.18	0.11	0.96	1.36
Uttarakhand	0.27	0.01	0.13	1.07	1.47
West Bengal	0.33	0.12	0.12	2.03	2.60
A & Nicobar Islands	0.4	0.00	0.05	0.10	0.56
Delhi	0.36	0.00	0.06	1.29	1.71
Puducherry	0.38	0.00	0.22	0.08	0.68

Source Authors calculations

Table 5 Statistical tools and analysis adopted to assess the degree of emissions

Parameter	Mean	SD	Extremely alarming >Mean + 2SD	Highly alarming > Mean + SD	Alarming > Mean	Moderate < Mean
EV-Livestock	0.27	0.14	0.55	0.41	>0.27	<0.27
EV-Rice field	0.04	0.05	0.14	0.09	>0.04	<0.04
EV- N fertilizers	0.08	0.05	0.18	0.13	>0.08	<0.08
EV - Residue burning	0.7	0.56	1.82	1.26	>0.7	<0.7
Emission Index	1.09	0.64	2.37	1.73	>1.09	<1.09

Source Authors' calculations

Table 6 Distribution of states in to "Extremely alarming", "Highly alarming", "Alarming" and "Moderate" greenhouse gas emitting category based on Emission

Extremely alarming >2.37		Highly alarming >1.73		Alarming >1.09		Moderate <1.09	
Punjab	2.68	Haryana	1.90	Tamil Nadu	1.54	Goa	1.02
West Bengal	2.60	Jharkhand	1.75	Uttarakhand	1.47	Jammu and Kashmir	0.92
Tripura	2.30	Delhi	1.73	Andhara Pradesh	1.41	Odisha	0.98
				Uttar Pradesh	1.36	Arunachal Pradesh	0.92
				Assam	1.11	Gujrath	0.86
				Bihar	1.11	Meghalaya	0.78
						Chattishgarh	0.73
						Karnataka	0.71
						Maharasthra	0.71
						Punducherry	0.68
						Manipur	0.62
						Nagaland	0.6
						Himachal Pradesh	0.59
						Mizoram	0.58
						A & Nicobar	0.56
						Kerala	0.49
						Sikkin	0.39
						Madhya Pradesh	0.37
						Rajasthan	0.3

Source Authors' calculations

Mean and standard deviation (SD) of the EI value were calculated for categorization of state for their GHG emission potential. If the EI value of a state is greater than or equal to mean+2 SD, it is grouped into "extremely alarming" emitting category. With an EI value of greater than or equal to the mean + SD and less than the mean+2 SD, the state is categorized as "highly alarming". An EI value greater than or equal to the mean and less than the mean + SD is considered "alarming". Finally, a state with an EI value less than the mean is considered "moderate" (Table 5). Accordingly, the states with an emission index of more than or equal to 2.37 fall into extremely alarming group, with emission index value of more than or equal to1.73 into highly alarming group, with an emission index value of more than1.09 into alarming group, and those below emission index value of 1.09 into under moderate group.

Punjab, West Bengal and Tripura call for an urgent need for emission reduction strategies (Table 6). Although it is politically difficult to impose emission taxes, the farmers can be incentivised to adopt technologies and practices that reduce GHG emissions.

Conclusion

The study has shown a significant impact of internalization of external costs of methane emissions on rice market. There is a considerable trade-off between emission tax and paddy production. The impact can be significantly higher in the near future owing to the increased emissions from paddy fields if GHGs mitigation strategies are not undertaken. Based on these findings, meaningful strategies for the adaptation and mitigation with technical, institutional, and policy interventions can be proposed.

Acknowledgement

The study was carried out with help of fellowship provided by Indian Council of Social Science Research (ICSSR), New Delhi for the period of two years from 2019-2020.

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Received 12 January 2023 Accepted 3 June 2023

Agricultural Economics Research Review 2023, 36 (1), 21-42
DOI: 10.5958/0974-0279.2023.00003.4

Bearing fruit or falling flat? The story of contract farming in India

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Abstract Contract farming (CF) holds potential to stimulate demand-led agricultural growth in India. CF is practiced by 5.5 lakh farmers. Government of India's 2020 CF law was withdrawn after extensive farmer protests. We scrutinize CF's empirical evidence, highlight research gaps, and discuss policy implications. Meta-analysis indicates CF can decrease input costs by 28%, improve productivity by 20%, and boost profits by 51%. Notably, outcomes like educational progress, nutritional security, gender equity, social inclusion and sustainability remain under-researched.

Keywords Contract farming, Meta-analysis, impact evaluation, evidence gap map, farmers' income, India

JEL codes Q02, Q13, Q18, D86, K12

Introduction

Demand-led agricultural production has grown faster than state-supported crop production (via guaranteed prices and procurement). For example, between 2011-12 and 2019-20, the gross value of output of fruits and vegetables increased threefold (33%), livestock fivefold (56%), and fisheries eightfold (91.25%), which is higher compared to that of cereals (12%) (NSO 2022). Since the 1991 reforms (LPG - Liberalization, Privatization, and Globalization of the Indian Economy), the growing middle-class population, rising per capita income, and women's participation in urban jobs have increased demand for high-value commodities (Pingali and Khwaja 2004). Higher demand for processed and ready-to-eat foods resulted in the rapid expansion of modern retail chains such as department stores, hypermarkets, and supermarkets (Deshingkar et al. 2003; Dev 2003). Although this transition provides farmers with the opportunity to earn higher returns (Joshi, Joshi, and Birthal 2006; Weinberger and Lumpkin 2005), constraints such as higher transaction costs, lack of access to quality inputs, credit, profitable markets, capital and information make it difficult for small farmers to seize this opportunity (Birthal and Joshi 2009; Bellemare, Barrett, and Just 2013; Berg 2013; Hanna, Mullainathan, and Schwartzstein 2014; Mcarthur and Mccord 2017).

Vertical coordination through contract farming is one of the many to catalyze demand-driven growth in agriculture. Thus, we investigate the pooled impact of participating in contract farming (CF) in this article.

Contract farming

CF is defined as an agreement between two or more parties covering access to a number of embedded services such as inputs, marketing, technology transfer, credit and insurance in exchange for crops at agreed price, quantity and quality of crop (Ton et al. 2018). The feature of CF is that it is a commercial agreement between seller (agent) and buyer (principal) who use the ability to negotiate a fair structure of monetary benefits to both parties from price risk of imperfect markets. Further, it is decentralized in nature allowing more scope for autonomous decision making and fostering a positive relationship between buyer and seller (Ton et al. 2018).

Theoretically, CF offers a win-win situation for farmers and agri-business companies. On one hand, time and cost-effective procurement of quality raw materials in the right quantity is a serious problem for the food processing industries (Asokan and Singh 2003). While on the other hand, small and marginal farmers face marketing problems and price risks. CF can be a solution to these problems (Eaton and Shepherd 2001; World Bank 2003). Therefore, CF is contemplated as an institutional solution to lessen the price and market risks, help in coping with imperfect factor markets and provide technical assistance through private extension services, which smallholder farmers could not obtain (Elabed et al. 2013; Bellemare 2015; Swain 2018). This ascertains access to finance and insurance lowering transaction cost to farmers.

Contrary to the aforementioned merits, monopsonistic and monopolistic exploitation by the dominant party, contract rigidity about quality and product specifications and leakage or side selling on account of opportunistic behavior of either party, can be viewed as flipside of CF system (Singh 2002a; Bellemare 2015; Fafchamps 2004; Minten, Randrianarison, and Swinnen 2009). It is also apprehended that the firms favor contracts with better resource-endowed large farmers due to scale of economies, thus might discriminate against smallholder farmers (Singh 2002b; Dileep, Grover, and Rai 2002). Such marginalization of resource-poor farmers leads to capitalist mode of agricultural development and reverse tendency, where marginal and small farmers lease land to large farmers (Kaur and Singla 2018).

CF in India can be traced back to the pre-independence period of the 19^{th} century, when opium, indigo, cotton, and tobacco were sourced through the contract system. Later, it expanded to commercial production of seeds and sugarcane in the 1960s, milk in the 1970s, and tomatoes and potatoes in the 1980s (Deshpande 2005). Now, contracts are used to produce staple crops such as wheat and basmati rice, cash crops such as cotton, oil palm and sugarcane, vegetables such as gherkins, tomatoes, chilli peppers, onions, potatoes, cucumbers, and baby corn, medicinal plants, flowers, milk, and poultry.

The evidence on efficiency and inclusiveness of CF depicts a mixed picture. This has further prompted an extensive debate on the role and impact of CF on income, employment, farm productivity and household welfare (Otsuka, Nakano, and Takahashi 2016; Barrett et al. 2012; Arouna, Michler, and Lokossou 2021; Ton et al. 2018).

In the Indian context, impact of CF has been evaluated for tomato cultivation in Punjab (Singh 2002a; Dileep, Grover, and Rai 2002), oil palm and gherkin cultivation in Andhra Pradesh (Dev and Rao 2005; Nagaraj et al. 2008; Kumar and Kumar 2008; Narayanan 2014), milk production in Punjab and Rajasthan (Birthal et al. 2008; Birthal, Joshi, and Gulati 2005), poultry in Andhra Pradesh (Ramaswami, Birthal, and Joshi 2006) and Maharashtra (Kalamkar 2012), papaya, marigold and broiler farming in Southern India (Narayanan 2014) and onion, okra and pomegranate in Maharashtra (Tripathi et al. 2018). Most of these observed that contract producers earned more profits than independent producers owing to higher yields and assured output prices. The institutional arrangement of CF was found to solve the problem of supply of quality raw material to the processors to a great extent (Dev and Rao 2005).

An apparent focal shift in government policy from mere enhancement of production towards agricultural marketing reforms can be noticed in India over the past decades. These reforms in agricultural markets aimed to eliminate the deficiencies of traditional marketing, which act as deterrents for the enhancement of farmer's incomes (Chand 2012) and to augment farmer's income through diversification into high value agriculture (Singla 2017). In India, private sector participation in agriculture was for the first time highlighted in National Agricultural Policy 2000. Later, steps were taken in Model Agricultural Produce Market Committee Act (APMC) 2003 to provide for direct selling by farmers to APMC registered CF firms and a code of conduct for CF or model contract was proposed to safeguard farmers' interests in the National Policy for Farmers 2007. Few more subsequent variants of these reforms were, the Model Agricultural Produce and Livestock Marketing (Promotion and Facilitation) Act, 2017 and Model Contract Farming Act, 2018 to facilitate direct contractual arrangements between the buyers and producers. Recently, the government floated a separate CF act named 'The Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020' to promote CF in India. However, the law was withdrawn following the year-long agitation by farmer lobbies.

Contract farming: determinants of muddling through for policy analysis[1]

There is a three-fold problem in the nature and execution of CF. First, the ability to negotiate guaranteed prices is tilted in the favor of buyers (principal) who are often big companies and processors along with lack of reliable estimates on yield and price of crop (Ton et al. 2018). The scarce data puts small farmers on a "take it or leave" basis, giving more powers to buyers in preparing contract documents. Second, the nature of CF is both formal and informal; formal contract agreements are often either oral or written. It is layered with informal elements and tacit understanding, allowing for too much discretion to provide the farmer with an incomplete contract (Michler and Wu 2020). Farmers are put in an unfair position because they must maintain a good relationship with the buyer, who can withdraw, terminate the contract prematurely, or fail to renew contracts if there is no safety protocol in place. This demonstrates that CF lacks a perfect legal system and third-party enforceable norms. Third, it reduces expected sense of ownership of farmers on their own land re-establishing the archaic feudal system of landlord-farmer relationship. The landlord here being the buyers (principal) having control over the resources of farmers, exercising monopoly bargaining power, also gain in lawsuits while having the choice to find many other growers (Wu 2006).

Public policy has to address this principal-agent problem and whether CF offers goals of equity and welfare or it is driven by mere business goals.

Tenancy contracts, sharecropping, fixed rental contracts, wage contracts, relational contracts, marketing contracts, and resource-providing contracts are the types of agricultural contracts (Eswaran and Kotwal 1985; Michler and Wu 2020; Menard and Shirley 2005; Ruml and Qaim 2021)**.** Traditional sharecropping is known to provide the greatest benefit of pooling un-marketed resources in the form of a tenant-landlord relationship, which is similar to a supervisor-manager role. Because it maintains a sense of ownership for both parties, the yield is higher. It is known to provide a dual incentive system to principal-agents, in which the buyer (principal) is rewarded for reporting and the grower (agent) is rewarded for production effort. Because agricultural output is highly sensitive to labour quality, this sharecropping arrangement is a win-win situation. Given the nature of incentive mechanisms, the most common contracts today are production, marketing, and resource-providing contracts, which have proven to be more successful in animal husbandry and high-value crops. Furthermore, due to the availability of information, market development, and technology, different contracts may coexist.

[1]See, Lindblom, Charles E. (1959)

In this study, we focus discussion on CF by investigating its implications using meta-analysis, evidence gap mapping, and Delphi analysis to guide policymaking. The purpose of this research is to better understand the crops and regions covered by CF in India, the services provided to farmers, the impact of CF on various outcomes, and the evidence gap that needs to be filled by future research. This research will serve as a one-stop shop for information on CF in India. Furthermore, public policy findings from Delphi analysis have been incorporated to solve the three-fold problem identified in CF research and to suggest future research directions.

Data and methodology

Meta-analysis

Meta-analysis is the statistical technique for synthesizing the findings of multiple studies for examining the same case by identifying the common effect using meta-regression model (Nelson and Kennedy 2009).

Search and eligibility criteria

A structured literature search was done to select studies which evaluated the impact of CF across India. Our selection criteria confined the literature base to quantitative studies only. Combinations such as "contract farming", "India", "vertical integration", "impact", "effect", "agriculture", "dairy", "vegetables", "poultry", "fruits" and "contract" were used for retrieving the studies from Scopus, IDEAS / REPEC, Agecon and Google scholar in February 2021. Additional reviews were added after snow-balling the reference list of studies that matched our criteria.

Study selection

All the retrieved studies were reviewed independently for their relevance screening the title and abstract. Figure 1 summarizes the key steps in the identification and screening process. The studies were subsequently screened for further relevance (title and abstract) narrowing down their number to 176. Full text screening was done for further exclusion. We only included those studies that documented the correlation, impact and constraints pertaining to CF in India. Henceforth, a total of 68 studies (consisting of 37 economic case studies, 17 dissertations and 14 quasi-experimental studies) were selected for our analysis (see Appendix 1 and 2 for details). Further, quasi-experimental studies (that used PSM, Heckman sample selection, IV, ESR, MTER, TE models) that properly identify the impact of CF (14) on welfare indicators of farmers were used for meta-analysis. All the included studies (68) were used for developing an evidence gap map using EPPI reviewer 4.

Data extraction

Data required for meta-analysis like effect size, standard error, t-values and sample sizes were extracted individually from each study. Study characteristics like contract year, company involved, crops contracted, and services provided by the company were also recorded. Data from 14 studies (impact evaluations) and 32 empirical instances were extracted with complete information.

Statistical analysis

We use response ratio (RR) as our outcome measure in meta-analysis. It is the ratio of the outcome of treated

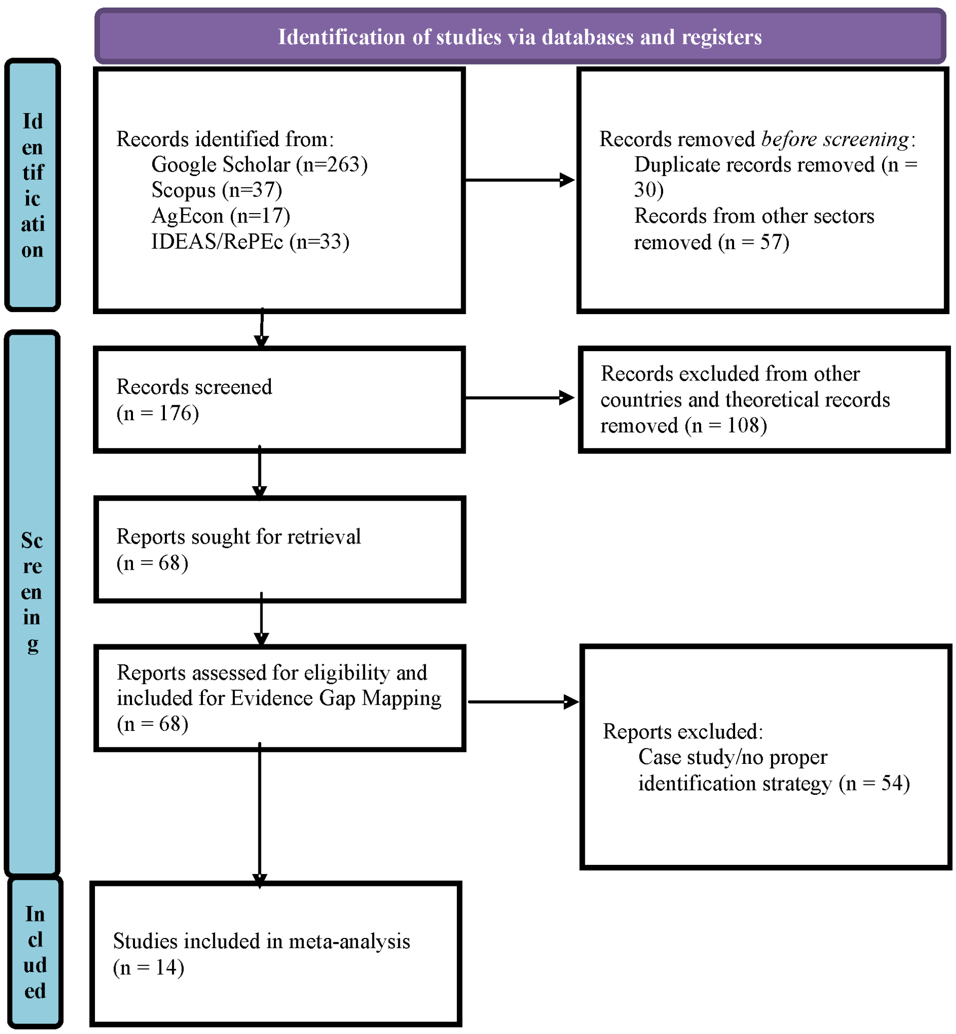

Figure 1 PRISMA flow chart of literature search and selection

and control groups. It is easy to interpret. An RR of 1.20 indicates a 20% average increase and an RR of 0.80 indicate a 20% average decrease in the treated relative to control. Estimation of the standard error of RR requires a t-value, which was recorded if mentioned in the article. If not, it was computed using the effect size and standard error (Ton et al. 2018). We conduct a random-effects meta-analysis using the Stata package "metan".

$$SE(RR) = Exp\left(\frac{\ln(RR)}{t}\right)$$

Evidence gap mapping

Evidence gap mapping (EGM) is an interactive matrix tool that provides a summary of studies conducted in a specific area. It synthesizes the available information and displays areas with abundant studies versus areas in need of additional research. It aids policymakers and researchers in developing evidence-based policies. In this study, EGM is used to analyze the existing "absolute and synthesized gaps" in CF research in India. The EPPI (Evidence for Policy and Practice Information) framework was used to create the EGM. The Evidence for Policy and Practice Information and Coordinating Center, Social Science Research Unit at University College London created the EPPI framework.

Delphi analysis

Findings and implications for public policy have been arrived at using Delphi analysis. In the first step, stakeholders are mapped with institutions, legal and policy regimes to arrive at relationships to provide a clearer picture of the policy levers on which different stakeholders operate to advance their objectives. In the second step, stakeholders are mapped based on power and influence as it helps understanding the relative power that stakeholders take in the policy process. Delphi analysis has been employed to suggest the scope for policy change in CF due to the existence of several types of stakeholders and their role in policy making.

Results and Discussion

Status of contract farming in India

Except in Bihar, Jharkhand, and Kerala, CF is popular throughout the country (Figure 2). Categorizing the states based on the number of crops involved in CF revealed that Karnataka (16 crops), Maharashtra (16 crops), Punjab (12 crops), and Andhra Pradesh (9 crops) have the highest level of contracts, while states like Uttar Pradesh, Assam, Jammu, Telangana, Chhattisgarh, Uttarakhand, Orissa, and West Bengal have the lowest. The remaining states are classified as having moderate CF. These findings (drawn from published studies) are supported by a recent nationally representative situation assessment survey (SAS) of agricultural households conducted by the Government of India's National Statistical Office (NSO). For the first time, questions about CF were included in the survey. Table 1 summarizes the findings. Punjab has approximately 11% of agricultural households that sell at least one crop to CF sponsors/companies, followed by Karnataka (2.3%), Himachal Pradesh (2.1%), Assam (1.9%), and Maharashtra (1.7%). Thus, our state mapping based on published studies, as well as the survey results, reveal a similar story about the spread of CF in India. According to the survey estimates, a total of 5,46,044 farming households in India produce/deal in CF.

Figure 2 also shows that majority of firms are concentrated in states with high levels of contracting (Appendix 3 and 4). It clearly shows a link between private players' involvement and crops grown under CF in the state. Favorable policies, geographic advantage, improved infrastructure, rural road networks, and irrigation facilities could all be reasons for this concentration in a developed state (Chakraborty 2009). In turn, corporate firms provide farmers with various resources that help them produce crops of the desired quality and quantity.

A commodity wise service index was created as an average of four indicators based on the extent of resources provided by contracting companies (Figure 3). The index's indicators were feed/fertilizer provision, seeds (including animal seeds), extension services, and credit. The highest service index was found in seed-based CF, indicating that contracting companies provide more than three resources to contracted farmers (Panel B, Figure 3). It was the lowest for contracts based on fruit crops. Among the combined services, 97% of the firms provided extension services (information), while only 24% provided credit to farmers (Panel A in Figure 3). According to the latest SAS, very few farmers have access to technical

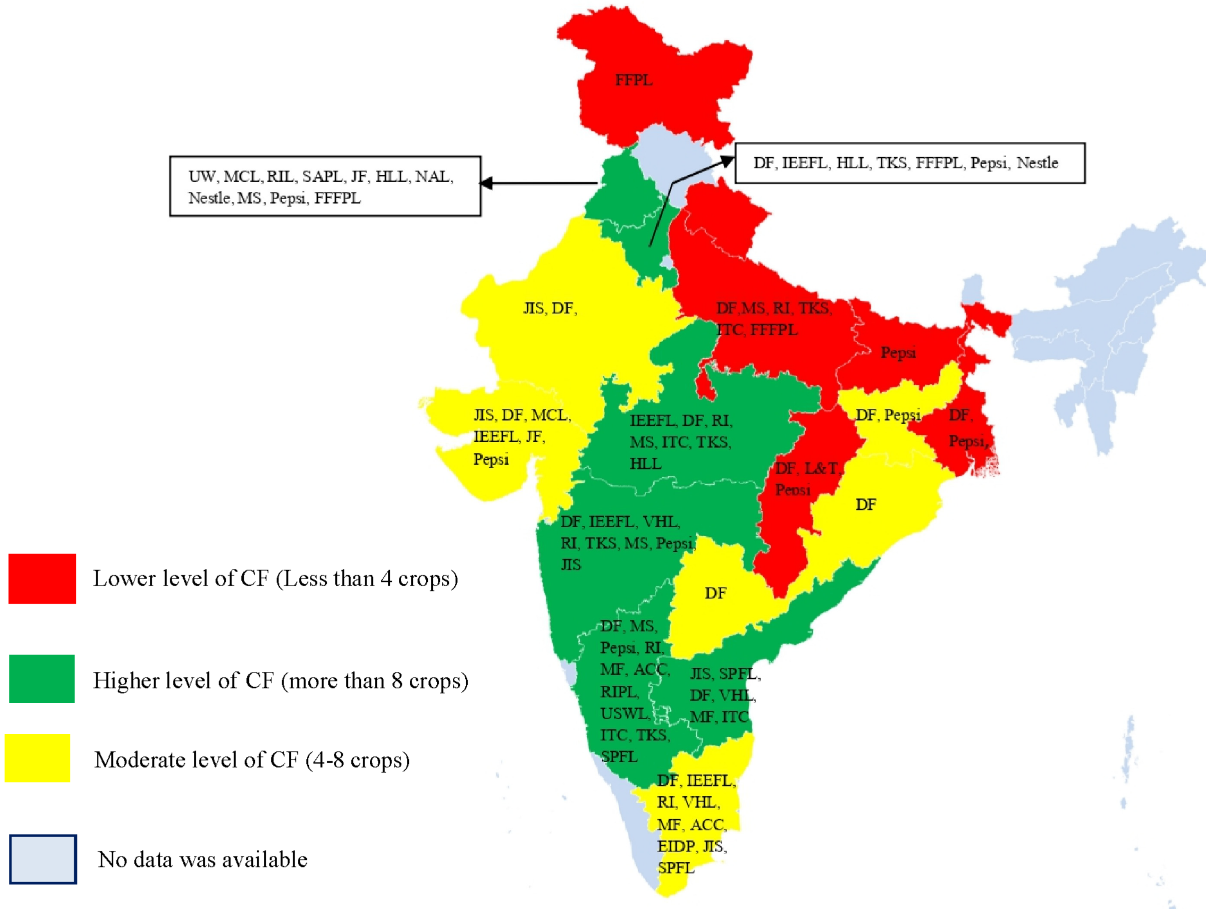

Figure 2 Overview of contract farming in India

Table 1 Farmers involved in CF in India

State	Crop producers selling at least one crop to CF sponsors/companies (%)	Estimated number of agricultural households (million)	Estimated number of households selling at least one crop to CF sponsors/companies
Punjab	10.6	1.5	155,513
Karnataka	2.3	4.3	97,752
Himachal Pradesh	2.1	1.0	21,588
Assam	1.9	3.1	58,898
Maharashtra	1.7	7.3	124,000
Kerala	0.6	1.5	8,800
Mizoram	0.6	0.1	458
Uttar Pradesh	0.5	7.8	38,792
Arunachal Pradesh	0.4	0.2	610
Andhra Pradesh	0.3	3.2	9,476
Haryana	0.3	1.9	5,719
Odisha	0.3	4.8	14,446
Telangana	0.3	2.7	7,967
Tripura	0.2	0.3	579
Jammu and Kashmir	0.1	1.3	1,256
Nagaland	0.1	0.2	192
Total	1.4	41.2	546,046

Source NSSO 77th round

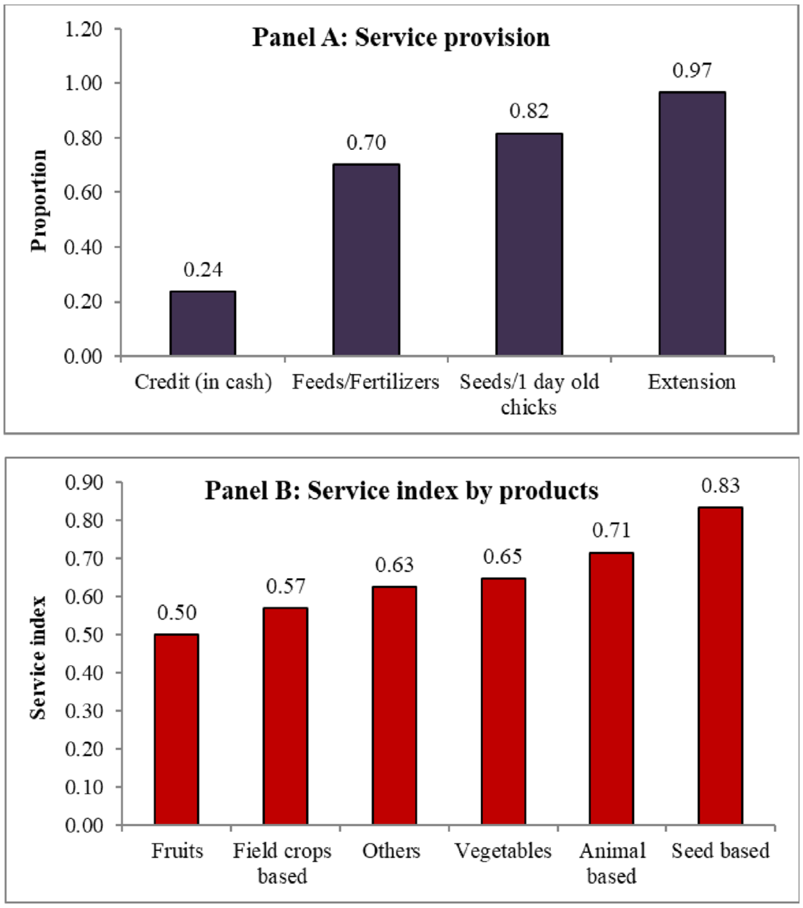

Figure 3 Service provision by contracting companies

information (around 10%) and institutional credit (around 60%), making CF more important because it corrects existing market (input, credit, information, and output) imperfections.

Meta-analysis

A number of quantitative and qualitative studies have confirmed CF's impact on farmer welfare (Gondalia, Zala, and Bansal 2017; Vandeplas, Minten, and Swinnen 2013; Kumar and Kumar 2008; Mishra et al. 2018a; Ramaswami, Birthal, and Joshi 2009; Mishra et al. 2018b; Singh 2002b). The presence of selection bias and confounders, however, limit the scope of these observational empirical studies in terms of developing internal and external validity (Bellemare and Bloem 2018). In other words, the actual impact cannot be established and extrapolated over time and space. Therefore, in our meta-analysis, we used only 14 studies that used quasi-experimental methods such as Propensity Score Matching (PSM), Heckman sample selection, Instrumental Variable (IV), Endogenous Switching Regression model (ESR), and Marginal treatment effect regression (MTER) to properly identify the impact estimates.

We have divided the impacts into intermediate and final outcomes based on the outcome achieved within a time frame. The intermediate outcomes include short-term impacts such as changes in resource accumulation, resource use, productivity, transaction cost reduction, labour employment, and production cost, while the final outcome includes long-term impacts such as changes in profit, income, consumption, education level, and so on.

Impact on intermediate outcomes

Input use

Contracting firms provide inputs because resource providing contracts are common in India. According to Figure 3, the majority of farmers obtained production inputs and technical know-how for using the inputs and technologies, as well as information about market prices and the required output quality. Technical assistance and access to quality inputs improves the knowledge base and modifies input market imperfections, resulting in optimal input utilization. Because these "factories in fields" are primarily involved in the production of high-value crops that are labor-intensive in nature, they increase employment.

There is a body of research examining the impact of CF on input usage. Figure 4 shows that contracting increased farm household employment by 58% in onion cultivation in Maharashtra, supporting the theory that contract crops are labour intensive. Only one Indian study identified the impact on fertilizer usage and farm household employment. CF reduced DAP usage by 11% and urea usage by 15% in baby corn production in Punjab and Haryana. Because excessive fertilizer use is directly related to groundwater contamination and soil degradation, market institutions such as CF can be a viable option for increasing yield while conserving the environment. Efficient fertilizer use will not only help improve soil conditions, but will also reduce fertilizer demand in the future.

Input cost

Because of imperfections in the input market, the value of marginal products of factors of production is less than the value of marginal input cost. As a result, inputs are used at a suboptimal level (underutilization of resources). Farmers receive inputs for free or at subsidized rates through market innovations such as CF, resulting in resource utilization in optimal or near-optimal way. The contracting terms not only shift the burden of input costs away from farmers, but also reduce the transaction costs that farmers incur when selling their products. The presence of a large number of middlemen in marketing channels raises transaction costs. As a result, CF can achieve the dual goals of lowering cultivation costs and transaction costs at the same time, ultimately increasing farmers' income.

Two studies (5 empirical examples) looked at the effect of CF on input costs. CF was found to reduce input

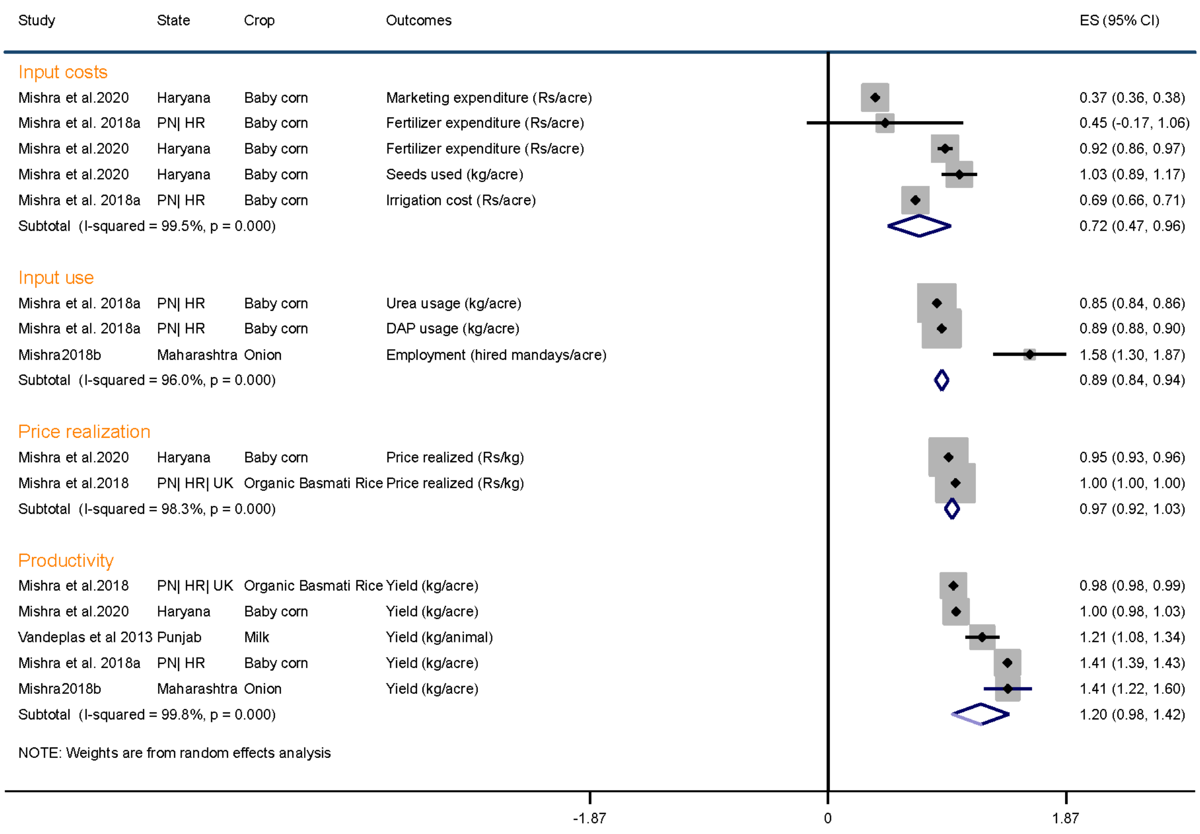

Figure 4 Forest plot on impact of CF on intermediate outcome

costs by 28% (RR= 0.72, 95% CI = 0.47 to 0.96). In Haryana, baby corn producers' fertilizer and market expenditures fell by 8% and 63%, respectively (Mishra, Mayorga, and Kumar 2020). Mishra et al. (2018b) discovered a 55% and 31% reduction in fertilizer and irrigation costs, respectively. The associated costs were reduced due to the reduction in fertilizer and water use. The rice-wheat cropping system has traditionally been water, capital, and energy intensive, resulting in soil degradation and water depletion. This renders the rice-wheat cropping system unsustainable. As a result, the maize-wheat cropping system may be an option for addressing sustainability and yield issues. CF has the potential to increase the penetration of micro irrigation and farm mechanization. Because CF is most prevalent in Punjab, Haryana, and Maharashtra (major ground water extractors), expanding the scope of micro irrigation, fertigation, and mechanization will solve the sustainability puzzle.

Price realization

CF is an institutional arrangement in which farmers are required to supply their produce to firms under pre-specified conditions specified in written or oral agreements. Farmers receive higher returns at a predetermined price due to lower input costs. As a result, it assists farmers in protecting themselves from price risk caused by market imperfections and price fluctuations.

Two studies look at how CF affects price realization. We find that realized prices decreased by 3% (RR=0.97, 95% CI = 0.92 to 1.03). Organic basmati rice producers in Punjab and Haryana reported no difference in price realization (Mishra et al. 2018a). However, in the case of baby corn, farmers saw a 5% decrease in price realized. Lower price realization decreases the farmer's willingness to engage in CF or breach the contract. As a result, steps must be taken to increase farmers' price realization.

Productivity

CF provides farmers with easy access to resources, credit, and extension services. It reduces the imperfection in both the input and output markets. Because the firm requires the desired quality of output, they provide inputs and technical know-how more effectively than government extension services (Minot 1986). The number of visits by extension agents has a positive impact on farm productivity (Bellemare 2010). Farmers who have access to technical information earn 12% more in net returns due to increased productivity (Birthal et al. 2015).

Five empirical cases reported impact on productivity. CF increased productivity by 20%, as predicted (RR= 1.20, CI= 0.98 to 1.42). In the case of organic basmati rice, a 2% decrease in crop productivity was reported (Mishra et al. 2018a).

Impact on final outcomes

Profit/net revenue

Growing evidence suggests two perspectives on the increase in profit of contract farmers. First, CF has emerged as a tool for capitalizing on the opportunity created by agricultural industrialization, which has changed consumer tastes and incomes. This change has resulted in an increase in demand for high value crops, hence CF can be extended to high value crops, resulting in increased farmers' income. Second, CF aids in the provision of free or subsidized inputs and extension services. It also reduces transaction costs and boosts productivity. As a result, the cost of production is reduced, and the profit is increased.

Ten empirical cases reported impact on profits. We find a pooled effect size of 51% increase in profit level (RR=1.51, 95% CI=1.25 to 1.78) (Figure 5). CF increased profit by two times for dairy farmers in Punjab (Birthal et al. 2009) and four times for okra growers in Maharashtra (Mishra et al. 2018b). All the studies included in the meta-analysis indicated an increase in profit. However, an exception was found in the work of Narayanan (2014), which reported a 44% decrease in profit for marigold farmers. Increasing farmer profit will not only help to diversify farmer income sources, but it may also provide impetus to shift from the rice-wheat system to another cropping pattern.

Income

Farmers in India's agricultural system face the challenges of inefficient input markets. Farmers' income is ultimately reduced as productivity declines and transaction costs rise. Evidence suggests that contract farmers not only have access to high-quality inputs and technical services, but also face lower transaction costs. Farmers who engage in CF typically

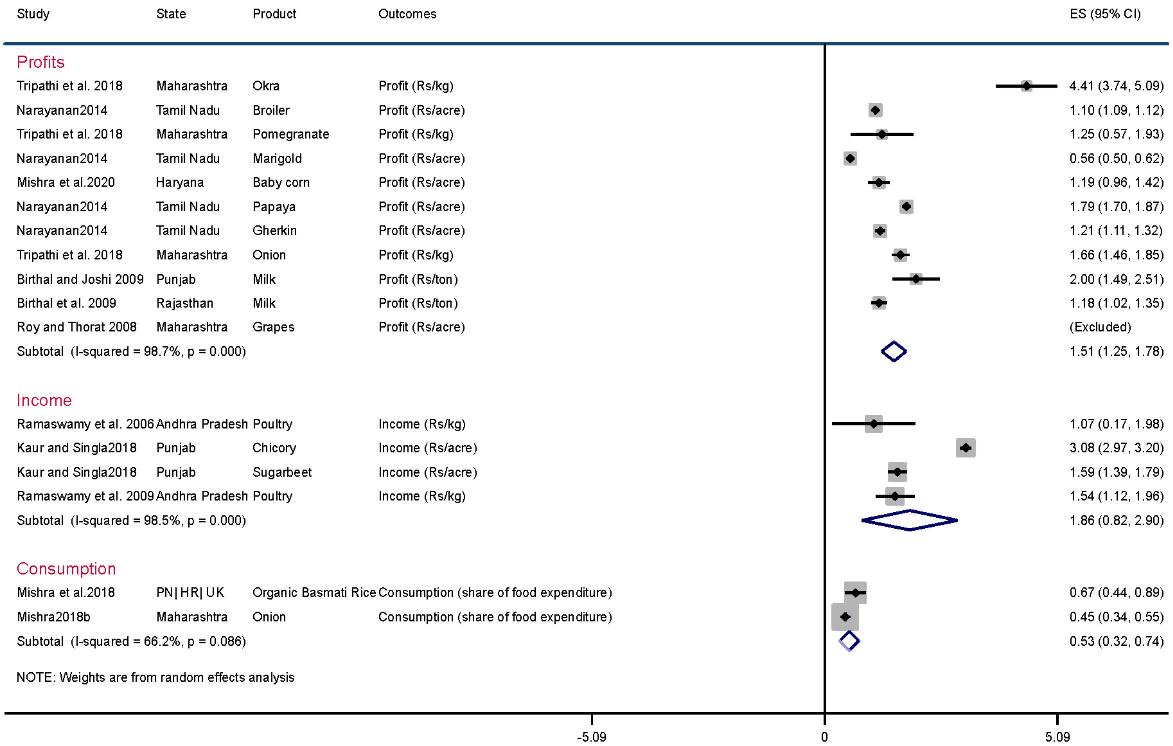

Figure 5 Forest plot showing the impact of CF on final outcomes

grow high-value crops that yield a higher return than staple crops. All of this adds up to significantly higher income for farmers.

Four studies assessed the impact of CF on incomes. We find 86% increase in the income received by contract farmers (RR=1.86, 95% CI= 0.82 to 2.90) (Figure 5). Kaur and Singla (2018) reported three times increase in income in chicory contract production. Increased income can incentivize the non-contract farmers for participating in CF and diversifying their production. Therefore, it can also motivate the migrated farmers or laborers to participate in CF at different stages (as an input provider/crop grower) at their places leading to reduced migration.

Consumption

According to Engel's law, as income rises, the proportion of income spent on consumption falls. This means that the income elasticity of consumption is positive but less than one.

Only two studies looked at how CF affected consumption. Consumption expenditure decreased by 47% (Figure 5), 55% decrease in consumption expenditure among onion growers and a 33% decrease in consumption expenditure among organic basmati farmers.

I^2 was very high in Figures 4 and 5, indicating significant heterogeneity among studies. The I^2 statistic was greater than 60% in both forest plots, indicating that more than 60% of variation is due to heterogeneity between studies. The variation can also be attributed to differences in contractual agreements that may have arisen as a result of the crops involved in the contracting.

To summarize, our analysis shows that farmers' participation in CF not only increases production but also reduces costs, which can contribute significantly to the government's goal of doubling farmers' income. CF as a marketing innovation reduces transaction costs and, as a result, marketing costs, ultimately lowering production costs. Increase in productivity and reduction in cost can aid in obtaining a higher return.

Assessment of publication bias

The scientific articles tend to be written and published only when there is a significant effect of the intervention. The inferences obtained in meta-analysis

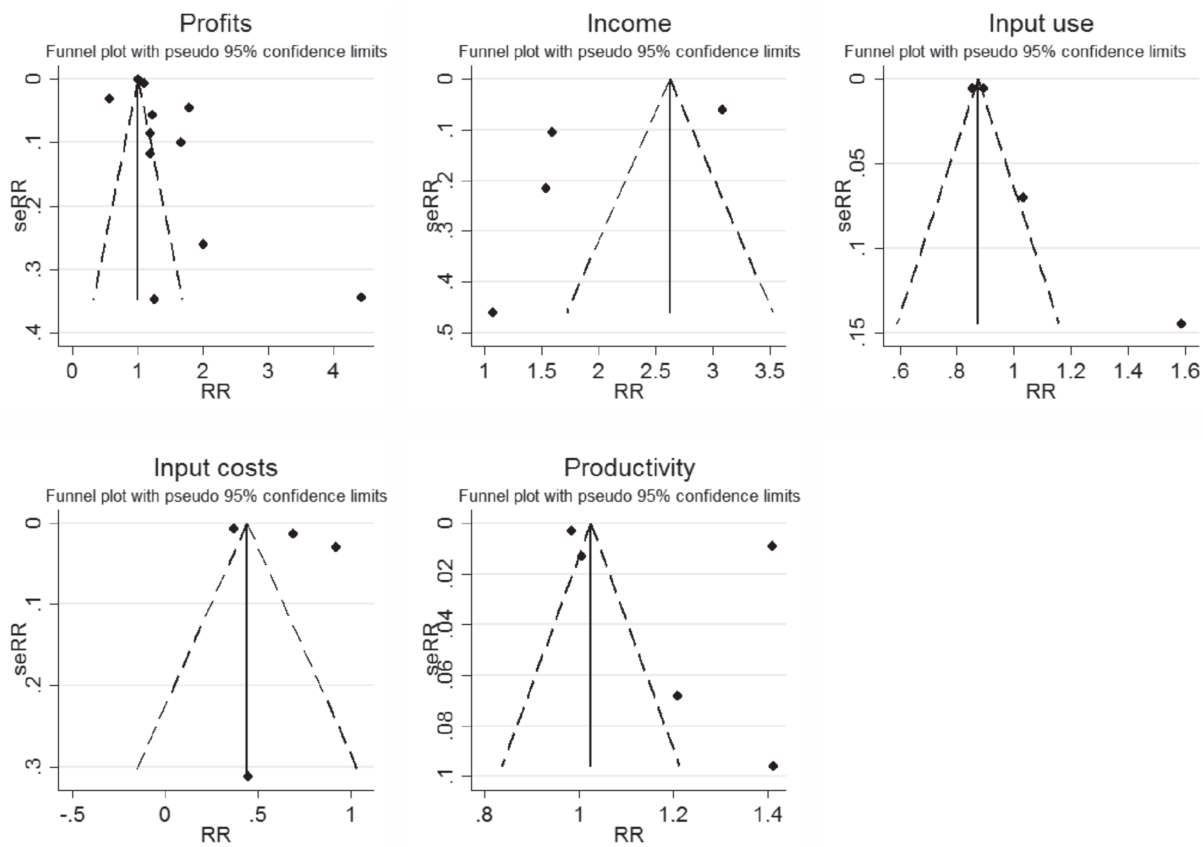

Figure 6 Funnel plot

are based on publications reporting the impact of CF. The publication bias was apparent in the pool of studies included for meta-analysis; only 5 out of the 32 empirical instances (16%) reported non-significant results. Furthermore, funnel plots and Egger's statistical test are used for formally assessing the publication bias present in the included literatures. Funnel plot shows the effect size against the precision. The symmetrical distribution of effect sizes around the average effect size (vertical axis) represents the absence of publication bias. Figure 6 depicts the publication bias using a funnel plot. Publication bias is evident as the plots are not symmetrical around the pooled effect size. The asymmetrical nature of the funnel plots is confirmed by the Egger's statistical test presented in Table 2. Positive and significant correlates show the presence of publication bias in all the studies included in meta-analysis.

Evidence gap map

The evidence gap map included 68 studies that met our inclusion criteria. We divided the map into states based on CF outcomes. The rows of the map represent Indian states, and the columns cover the study type. A state-outcome cell is assigned to each study. 68 studies are classified according to their economic outcomes. The number of mosaics increases as the number of studies in a given state-outcome cell increases. According to Figure (7), the majority of the work is done in Punjab, Karnataka, Andhra Pradesh, Maharashtra, Haryana, and Tamil Nadu. There are fewer studies in Uttar Pradesh, Gujarat, Uttarakhand, West Bengal, Rajasthan, Jammu and Kashmir, and Madhya Pradesh. There were no studies found for states such as Bihar, Jharkhand, Chhattisgarh, and Kerala. However, recent NSSO surveys (Government of India 2019) have revealed that contracting companies are involved in crop production in Kerala. As a result, a pool of literature reviewing the impact of CF in these states is the need of the hour.

The majority of the studies included are empirical in nature that compare the outcomes of contract and non-contract farmers. In the country, very few impact evaluations or quasi-experimental studies that actually

Table 2 Results from Egger's test: Test for asymmetry of funnel plot

Outcomes	Empirical instances	Test of H0: no small-study effects	Slope	Bias	Root MSE
Profit	10	P = 0.42	1.07***	2.84	9.03
			(0.06)	3.32	
Income	4	P=0.31	3.35**	-8.71	7.16
			(0.65)	6.45	
Input use	4	P=0.33	0.85***	3.82	4.00
			(0.02)	2.99	
Input cost	4	P=0.72	0.46*	-4.07	18.80
			(0.11)	10.00	
Productivity	5	P=0.44	0.97***	12.45	23.20
			(0.09)	14.13	

***, **,* indicate statistical significance at the 1, 5 and 10% level, respectively.

Figure 7 Evidence Gap Map

Note Interactive EGM can be found here. https://github.com/adeeth07/adeeth07.github.io/blob/master/EVG%20Map%20-%20CF.html

identify the impact of CF are conducted. Because empirical studies frequently lack external and internal validity, the emphasis should be shifted to experimental and quasi-experimental studies to determine the true impact of CF. The evidence gap map clearly shows that the majority of empirical analysis has focused solely on the economics of production or cultivation, as well as their associated features. Besides, long-term consequences of CF should be studied, such as the impact on educational attainment, nutritional security, diversification, sustainability, livelihood resilience, gender roles, land ownership, savings, and capital formation.

Delphi analysis

As discussed earlier in the methodology, this analysis is found suitable for stakeholder analysis to design an inclusive legal-policy environment for CF incorporating long-term development goals such as equity, environmental sustainability, resilience and farmer empowerment.

Step 1: Mapping of stakeholders, policies and institutions

The change-drivers: These stakeholders are key policy change advocates. They are large farmers, political parties, NGOs, agri-business corporates, food industry processors, middlemen, government and bureaucratic apparatus. The change drivers show up as proactive players and promoters in the stakeholder analysis (Step 1 and 2). Agri-business corporate lobby exists in very high value crops like gherkins, cotton, oil palm in which their authoritative price setting method often goes unquestioned, they also demand corporate farming be implemented which is not legal in India (Singh 2006). For instance, farmer's organizations and certain NGOs act as pressure groups engaging in protests and demand policies to be implemented. The government here as a change driver can bring about sweeping changes in the system.

Status quo actors: Small farmers, lower level bureaucracy i.e. Mandi and APMC officials, input dealers, consumers and banks show up as actors who prefer status quo (or) those who do not advocate policy change. They show up as status quo players and apathetics in the stakeholder analysis (Step 1 and 2). They do not aggressively support policies like CF and the gains and losses do not matter to them much. They have a passive role in bringing policy change.

Incrementalist actors: Such stakeholders can be placed at the center of the policy continuum since they serve to reduce the magnitude of the present problem arising out of conflicting interests. The multilateral organizations like the FAO, World Bank, CGIAR, ICAR research institutes *etc.* are part of the external actors as they are concerned with the interests of the farmers, they often come out with policy documents and research aimed to reduce the stress around the issue.

High resource actors (veto players): Government bodies (Union and State Ministries), the bureaucracy, political parties, agri-business corporates are high resource veto players who can decisively influence the policy setting process in our analysis (Step 1 and 2).

Step 2: Mapping of stakeholders based on power and influence

Promoters: In terms of policy intervention, the high-resource actors who possess high power and high interest have been categorized as promoters. For instance, the government has significant interest and power to safeguard the farmers. Similarly, state governments are significantly powerful in terms of their ability to change state laws and represent the high interest of farmers.

Latent: The small farmers and consumers have been categorized in the latent category because they are highly powerful in terms of the voting block that they represent.

Apathetic: Organizations such as FAO are highly technocratic organizations who provide know-how or finances, are categorized as apathetic actors as their power is limited in policy-making. They look at larger policy frameworks than ground level realities that affect the policy decisions.

Defenders: Large farmers' association, NGO's and cooperative societies can be collectively grouped as defenders due to their high interest in bringing about policy change.

Stakeholder analysis

Scope for policy change: We see substantial overlap between the change driver's and high resource veto players making policy change possible. The final analysis presented by Delphi suggests that there is pressure to change policy and is further translated into willingness to change policy at the level of union and state governments.

Consensus on the nature of policy change: One of the reasons for the failure of the farm bill is the lack of consensus. The objectives of Farmers (Empowerment and Protection) on Price Assurance and Farm Services Bill 2020 were elimination of middlemen, liberalization of trade and miscellaneous fees at various market yards. Delphi study presents the most influential policy-maker as the union and state government, who is capable of resolving conflicts of interest. However, the bill became a point of contention for the government owing to its lack of enthusiasm on inclusive consultation and debates. The lack of grassroots level consultation with farmers, media outreach and parliamentary debates by the government caused the farmers and traders to fight for the cause of MSP (Minimum Support Price) rather than see the holistic merits of the law. Furthermore, the three-level dispute resolution in the bill shows the creation of yet another bureaucratic structure with no significant guarantee on efficacy of time and costs of grievance redress.

Conclusion

Farmers' protests in India against new CF laws rekindled debate about the benefits and drawbacks of CF. This research is an attempt to understand what we know about CF and what we don't. We compile all CF research studies and reviews to map the states, crops, and companies involved in CF, evaluate the pooled effect of CF on various outcomes, and present evidence gaps. In addition, we use Delphi analysis to propose a policymaking roadmap.

We discovered that CF is concentrated in states such as Karnataka, Maharashtra, Andhra Pradesh, and Punjab, while it is scarce in the rest of the country, especially eastern states such as Bihar and Jharkhand. In India, an estimated 5.5 lakh farmers are involved in CF. The majority of contracts in India were found to be resource-providing ones. It was found that 97% of contracting firms provided extension services, while only 24% provided credit to farmers. According to a meta-analysis of credible (but limited) quasi-experimental studies, CF reduced farmers' input use by 11-15%, reduced input costs by 28%, increased productivity by 20%, and increased net revenue/profits by 51%. The analysis indicates that CF is extremely beneficial to farmers; however, small number of studies and the lack of experimental evidence, necessitates more credible impact evaluations.

The majority of the empirical literature has concentrated solely on the economics of production or cultivation and their associated characteristics. Future research should focus on defining the long-term effects of CF, such as the impact on educational attainment, nutritional security, diversification, sustainability, livelihood resilience, saving, and capital formation.

Thus, in CF laws, public policy must address the principal-agent problem. It must also provide equity, welfare, and long-term development goals through private participation. Following farmer agitations, the policy failed to achieve consensus on the goals and nature of CF, resulting in the withdrawal of nationalized CF law in India. Massive media outreach, inclusive debates in parliament, and grassroots stakeholders have emerged as critical factors determining the law's success or failure. In addition to business goals, the bottom-up approach and regulatory mechanisms are critical to the policy process. Karnataka's citizen-centric governance model (SAKALA) has been cited as a model for developing accountability and grievance redress mechanisms.

Disclaimer

The perspectives presented in this article are solely those of the authors and are formulated based on their individual capacities. Such viewpoints do not necessarily represent the positions or opinions of any affiliated institutions.

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Received 13 November 2022 Accepted 23 February 2023

Appendices

Appendix 1 Overview of the studies included in the present study

Sl. No.	Author	Year	State	Product collection	Year of data
1	Dileep et al.	2002	Haryana	Tomato	1989
2	Dev and Rao	2005	Andhra Pradesh	Oil Palm, Gherkin	2001-02
3	Tripathi et al.	2005	Haryana	Potato	2003-04
4	Ramaswami et al.	2006	Andhra Pradesh	Poultry	2002-2003
5	Chidananda	2007	Karnataka	Broiler	2005
6	Kumar J and Kumar P	2008	Karnataka	Gherkin, Babycorn, Paddy, Groundnut, Ragi, Chilli, Sunflower	2000
7	Nagraj et al	2008	Karnataka	Babycorn, Chilli	2005-06
8	Roy and Thorat	2008	Maharashtra	Grapes	2005
9	Sharma	2008	Punjab	Basmati rice, Wheat, Rice	2007
10	Sharma	2008	Rajasthan	Bottlegourd	2015-16
11	Birthal et al.	2009	Rajasthan	Milk	2005
12	Birthal and Joshi	2009	Punjab	Milk (Direct contracting and inermediate contract)	2003
13	Ramaswami et al.	2009	Andhra Pradesh	Poultry	2002-2003
14	Swain	2011	Andhra Pradesh	Rice seeds, Gherkin	2008
15	Kalamkar	2012	Maharashtra	Broiler	2009-10
16	Kole	2012	Maharashtra	Onion seed, Cotton seed, Potato, Onion	
17	Chandakavate et al.	2013	Karnataka	Green chilli	2005-06
18	Goel	2013	Punjab	Basmati Rice	2010-11
19	Vandeplas et al	2013	Punjab	Milk	2008
20	Narayanan	2014	Tamil nadu	Broiler, Gherkin, Marigold, Papaya	2009-2010
21	Sharma	2014	Punjab	Seedpotato, Basmati	2012
22	Mohan kumar	2015	Karnataka	Broiler	2014
23	Swain	2016	Andhra Pradesh	Hybrid paddy seeds	2009
24	Gondalia et al	2017	Gujarat	Potato	2014-15
25	Kumar	2016	Punjab	Basmati, Oilseeds, Potato seeds	NA
26	Johny et al	2018	Telangana	Hybrid seeds production	2017
27	Kaur and Singla	2018	Punjab	Sugarbeet, Chicory	2016
28	Mishra et al.	2018a	Punjab and Haryana	Babycorn	2016
29	Mishra	2018b	Maharashtra	White Onion	2016
30	Mishra et al.	2018	Punjab, Uttarakhand and Haryana	Organic basmati rice	2016
31	Swain	2018	Telangana	Hybrid paddy seeds and Gherkin	NA
32	Tripathi et al.	2018	Maharashtra	Okra, Pomegranate, Onion	2016
33	Vicol	2018	Maharashtra	Potato	2013-14
34	Harish, N	2019	Karnataka	Gherkin, Watermelon, Tomato	NA
35	Kar et al	2019	Uttar Pradesh	Basmati rice	2017-18
36	Neelkantappa	2019	Gujarat	Potato seed	NA
37	Dsouza	2020	Karnataka	Okra	2017-18
38	Mishra et al.	2020	Haryana	Babycorn	2016
39	Bhanot et al.	2021	Maharashtra	Tomato	2016-17
40	Kumar and Tripathi	2021	Maharashtra	Okra	2016

Appendix 2 Overview of the thesis included in the present study

Sl. No.	Author	Agricultural University	State	Products	Year of data collection
1	Arun Kumar S	IARI, Delhi	Tamil Nadu	Coleus, cotton	NA
2	Ananth, G. S.	UAS, Bengaluru	Karnataka	Potato	2012-13
3	Viral kumar J Patel (Project)	Navsari Agricultural University Navsari	Gujarat	NA	2015
4	Ankur Mathur	G.B. Pant University of Agriculture and Technology, Pantnagar	Uttarakhand	Capsicum	2008
5	N.N Keshavmurthy	UAS, Dharwad	Karnataka	Gherkin	2004-05
6	S. Sridhar	UAS, Dharwad	Karnataka	Maize	
7	Arun Kumar S	UAS, Dharwad	Karnataka	Potato, Tomato, Chilli	2000-01
8	Rakesh Nanda	Sher-e-Kashmir University of Agricultural Sciences and Technology	Jammu	Basmati Rice	2012
9	Shivanand S. Hiremath	GKVK, Bengaluru	Karnataka	Babycorn	2009-10
10	Pramod M. Chandakavate	GKVK, Bengaluru	Karnataka	Green Chilli	2005-2006
11	Rajat Sharma	CCS Haryana Agricultural University, Hisar	Haryana	Sugarcane, Vegetables, Mushroom	NA|
12	Gyan Ranjan Majhi	OUAT, Bhubaneswar	Odisha	Sugarcane	2011-12
13	Mallikaarjuna M.N.	GKVK, Bengaluru	Karnataka	Potato	2012-13
14	Neelkantappa P	IARI, Delhi	Gujarat	Potato	2018-19
15	Shrikantha Tirakappa Mulimani	GKVK, Bengaluru	Karnataka	Seeds production (Rigde gourd, bitter gourd, chilli, tomato)	NA
16	Keshavmurthy N.N	UAS, Dharwad	Karnataka	Gherkin	2004-05
17	Shiraz Zakir	UAS, Dharwad	Karnataka	Broiler	2007-08
18	Arun Kumar S	IARI, Delhi	Tamil Nadu	Cotton	NA
19	Varun Miglani	Gokhale Institute of Politicas and economics	Maharashtra	Chip grade potato, white onion	2012-13
20	Mahesh Pratap Singh	JNU, Delhi	Punjab	Basmati, Sunflower, Hyola, Maize	NA

Appendix 3 Crops involved in contract farming

Sl. No.	States	Crops
1	Andhra Pradesh	White viagra, fruits, vegetables, flowers, gherkins, cocoa, oil palm, broiler, rice seeds
2	Gujarat	Processing of aloe vera and medicinal plants, sesame seeds, potato, potato seeds
3	Orissa	Seeds (paddy, ragi, green gram, arhar, groundnuts), sugarcane and eucalyptus
4	Rajasthan	Exotic vegetables, safflower, Barley, Guar
5	West Bengal	Chip quality potato
6	Karnataka	Aswagandha, Dhavana, marigold, caprica, chilli, coleus, gherkin, safflower, babycorn, ragi, sunflower, fruits, seed production, potato, Broiler, barley
7	Maharastra	Soyabean, fruits, vegetables, cereals, spices, pulses, sugarcane, oranges, grapes, pachouli, safflower, broiler, cotton seeds, onion seeds, chip quality potato, white onion

Contd...

8	Madhya Pradesh	Wheat maize, fruits, vegetables, cereals, spices, pulses, soyabean, garlic, white onion, safflower
9	Punjab	Tomato, chilly, barley, basmati maize, basmati groundnut, potato, tomato, green vegetables, exotic vegetables, sesame seeds, potato seeds, oilseeds
10	Tamil Nadu	Cotton, paddy, Maize, Gherkin, coleus
11	Chhattisgarh	Safed musli tomato, safflower
12	Uttrakhand	Guar gum, capsicum
13	Haryana	Turmeric, mentha, sunflower, white musli, potato, vegetables, mushroom, sugarcane
14	Uttar Pradesh	Basmati rice
15	Telangana	Seeds production, hybrid paddy, gherkin
16	Jammu	Basmati rice

Appendix 4 State wise operation of private companies

Sl. No.	Companies	States
01	Jain Irrigation system (JIS)	Gujarat, Andhra Pradesh, Rajasthan, Tamil Nadu, Maharashtra
02	Mahindra Subhlabh (MS)	Madhya Pradesh, Uttar Pradesh, Punjab, Karnataka, Delhi, Maharashtra, Uttarakhand
03	Pepsico(Pepsi)	West Bengal, Jharkhand, Maharashtra, Gujarat, Karnataka, Haryana, Bihar, Chhattisgarh,
04	Nestle	Punjab, Haryana, Rajasthan
05	Field Fresh Foods Private Limited (FFFPL)	Punjab, Jammu and Kashmir, Himachal, Haryana, WesternUttar Pradesh, Uttarakhand
06	Nijjer Agro foods Limited (NAFL)	Punjab
07	ITC agrifoods (ITC)	Uttar Pradesh, Madhya Pradesh, Karnataka, Andhra Pradesh
08	Tata Kisan Sansar (TKS)	Madhya Pradesh, Haryana, Karnataka, Maharashtra, Uttar Pradesh, Punjab.
09	EID Parry (EID)	Tamil Nadu
10	Hindustan Levers Limited (HLL)	Punjab, Haryana, Madhya Pradesh
11	Ugar Sugar Works Ltd. (USWL)	Karnataka
12	Appachi Cotton Company (ACC)	Tamil Nadu, Karnataka
13	Reitzel India Private Limited	Karnataka
14	Jamnagar Farms Pvt. Ltd. (Subsidiary to Mukesh Ambani Group)	Punjab and Gujarat
15	Reliance Groups	Punjab
16	Satluj Agricultural Pvt. Ltd	Punjab
17	Maxworth Fruits	Andhra Pradesh, Karnataka and Tamil Nadu
18	Venkateshwara Hatcheries Ltd	Tamil Nadu, Andhra Pradesh, Maharashtra
19	United Breweries	Punjab
20	Suguna Poultry Farm Ltd. (SPFL)	Tamil Nadu and Andhra Pradesh
21	Rallis India (RI)	Punjab, UP, MP, Maharashtra, Karnataka, Tamil Nadu
22	Ion Exchange Enviro Farms Ltd. (IEEFL)	Tamil Nadu, Madhya Pradesh, Gujarat, Haryana, Maharashtra
23	McCain Ltd (ML)	Gujarat, Punjab, Lahaul Spiti
24	Larsen and Turbo (LandT)	Chhattisgarh
25	Daulat Farms (DF)	Chhattisgarh, Odisha, MP, UP, Maharashtra, WB, Haryana, Jharkhand, Rajasthan, Telangana, TN, Karnataka, Gujarat, Kerala, Uttarakhand

Appendix 5 Combination of services embedded in contracts

Study	Year	Product	Feeds/ Fertilizers/ Bio-fertilisers	Seeds/ one day old chicks	Extension	Credit (in cash)
Arun Kumar S	2002	Coleus	Y	Y	Y	N
		Cotton	N	N	Y	N
Arun Kumar S	2002	Potato	N	N	Y	N
		Tomato	N	Y	Y	N
		Chili	N	N	Y	N
Dileep et al.	2002	Tomato	Y	Y	Y	NA
N.N Keshavmurthy	2005	Gherkin	Y	Y	Y	Y
Rajat Sharma	2005	Sugarcane	Y	Y	Y	N
		Vegetables	Y	Y	Y	N
		Mushroom	Y	Y	Y	N
Tripathi et al.	2005	Potato	Y	Y	Y	N
Pramod M. Chandakavate	2006	Green Chilli	Y	Y	Y	NA
Ramaswami et al.	2006	Poultry	Y	Y	Y	N
Chidananda	2007	Broiler	Y	Y	Y	Y
Ankur Mathur	2008	Capsicum	N	Y	N	N
Kumar J and Kumar P	2008	Gherkin,	NA	NA	NA	NA
		Babycorn,	NA	NA	NA	NA
		paddy	NA	NA	NA	NA
		Groundnut	NA	NA	NA	NA
		Ragi	NA	NA	NA	NA
		Chilli	NA	NA	NA	NA
		Sunflower	NA	NA	NA	NA
Nagraj et al	2008	Babycorn, chilli	Y	Y	Y	N
		Chilli	Y	Y	Y	N
		Babycorn	Y	Y	Y	N
		Chilli	Y	Y	Y	N
Roy and Thorat	2008	Grapes	Y	Y	Y	N
Sharma	2008	Basmati rice, wheat, rice, Bottlegourd	Y	Y	Y	Y
S. Sridhar	2008	Maize	N	N	Y	N
Birthal et al.	2009	Milk	Y	N	Y	N
Birthal and Joshi	2009	Milk	Y	N	Y	Y
Ramaswami et al.	2009	Poultry	Y	Y	Y	N
Shivanand S. Hiremath	2010	Babycorn	Y	Y	Y	N
Swain	2011	Rice seeds	Y	Y	Y	N
		Gherkin	Y	Y	Y	N
Kole	2012	Onion seed	Y	Y	Y	Y
		cotton seed	Y	Y	Y	N
		Potato	Y	Y	Y	Y
		onion	Y	Y	Y	Y
Chandakavate et al.	2013	Green chilli	Y	Y	Y	N
Goel	2013	Basmati	NA	Y	Y	NA

Contd...

Vandeplas et al	2013	Milk	Y	N	Y	Y
Ananth, G. S.	2014	Potato	N	Y	NA	N
Narayanan	2014	Broiler	N	Y	Y	N
		Gherkin	Y	Y	Y	N
		Marigold	N	Y	Y	N
		Papaya	NA	NA	Y	N
Sharma	2014	Seed potato	Y	Y	Y	Y
		Seed potato, Basmati	Y	Y	Y	Y
		seed potato	Y	Y	Y	Y
		Seed Potato	N	Y	Y	N
Mohan Kumar	2015	Broiler	Y	Y	Y	NA
Viral Kumar J Patel	2015	NA	Y	Y	Y	NA
Kumar	2016	Basmati, oilseeds, Potato seeds	Y	Y	Y	Y
Rakesh Nanda	2016	Basmati Rice	N	N	Y	N
Swain	2016	Hybrid paddy seeds	N	Y	Y	N
Gondalia et al	2017	Potato	NA	Y	Y	NA
Kaur and Singla	2018	Sugarbeet	Y	Y	Y	N
		Chicory	N	Y	Y	N
Johny et al	2018	Hybrid seeds production	N	Y	Y	N
		Gherkin	Y	Y	Y	N
Mishra et al.	2018	Organic basmati rice	NA	N	Y	N
Mishra et al.	2018a	Babycorn	N	Y	Y	N
Tripathi et al.	2018	Okra	Y	N	NA	N
		Onion	N	Y	Y	N
Vicol	2018	Potato	Y	Y	Y	Y
Kar et al	2019	Basmati rice	Y	Y	Y	N
Dsouza	2020	Okra	Y	Y	Y	N
Mishra et al.	2020	Babycorn	N	N	Y	N
Kumar and Tripathi	2021	Okra	Y	Y	N	N

Agricultural Economics Research Review 2023, 36 (1), 43-51
DOI: 10.5958/0974-0279.2023.00010.1

Marine fisheries insurance in India: retrospect and prospects in the context of climate change

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Abstract Fishers often face risks to their life and fishing assets. Sudden changes in weather in the form of cyclones, tsunamis, collision of fishing vessels, and accidental firings constitute major perils that affect fishers. The weather fluctuations lead to an unstable income flow. Marine fishing insurance may help fishers protect themselves against climate risks. The insurance in fisheries sector has several learning lessons from the crop insurance schemes. This paper reviews the status of marine fisheries insurance in India and prospects for reforming it in the light of the experiences of the crop insurance schemes. The study uses both primary and secondary data. The primary data were collected using a snowball sampling technique from 200 fishermen in Kerala; 100 each from traditional fishers and trawl fishers. The data was supplemented by a case study of the *Njarakkal-Nayarambalam* Fishermen Welfare Cooperative Development Society in Ernakulam, Kerala which facilitates insurance coverage to traditional fishers. Also, three focused group discussions with the fishermen were carried out. The leaning lessons for fisheries insurance from the crop insurance in Kerala were derived following a literature review. All the traditional vessels (100%) in the sample were insured due to the operation of *Matyafed*, a cooperative venture supported by the Government of Kerala, which provides credit to the traditional fishermen where the insurance is bundled with credit. Vessels insurance has only marginal coverage with trawl fishers. The main reasons for the low subscription are high premiums, inadequate coverage of the loss, and previous experience of delays in settlement of indemnities. Lack of suitable insurance products and difficulty in verifiability affects also affects its deepening. Further, fishers perceive insurance as an additional expenditure, and are of the opinion that the community would take care of the loss to a certain extent. The weather index-based insurance as in the case of crops is an alternative solution.

Key words fisheries insurance, climate change, sustainable fishing, crop insurance, livelihood

JEL codes G220, Q120, Q140,

Marine capture fishing is a profession with a high element of risk and uncertainty. The consequent income instabilities affect the lives and livelihoods of fishers. One of the most important institutional mechanisms for addressing individualised risks is the development of an insurance market, which aids in risk transfer and provides relief to fishers in perilous situations. The demand for institutional mechanisms to manage risks and uncertainties in marine fishing industry has increased in recent years for a number of reasons. First, technological advances in propulsion, gear design, navigation systems, and information and communication have intensified investments and have increased the value at risks associated with marine fishing activities (Parappurathu et al. 2017). Risks in fishing include the loss or damage to fishing vessels, equipment and gear in operation, fish loss as well as increased fatalities at sea. More than 24,000 fishermen are killed every year due to damage to vessels and gear, according to the International Labour Organization (Parappurathu et al. 2019). The weather risks in marine fisheries take several forms—cyclones, storms, and changes in sea level temperature—affecting fishers' livelihoods economically, socially, environmentally, and even physically (Devi et al. 2018). The World Meteorological Report estimates that during the past 50 years, an average weather, climate, or water-related calamity has claimed 115 lives / day and resulted in daily losses of US$ 202 million (WMO 2021). In 2020, India lost $87 billion due to natural disasters such as tropical cyclones, floods, and droughts (WMO 2021). Cyclone Ockhi, which hit the Kerala-Tamil Nadu coast in 2017, severely affected the marine fisheries.

In addition to risks due to natural hazards, the open-access, multi-gear, multi-species context, and intense competition lead to income risks due to the problem of disguised unemployment, declining catch rates, declining yields, and overfishing. Overfishing leads to the destruction of fish stocks (Kurien & Achari 1994; Devaraj & Vivekanandan 1999; Parappurathu et al. 2017). Hence, it is a source of income risk. Its economic impacts fall disproportionately on small-scale fisheries (SSF) and fishermen. Further, climate change and the resulting increase in the number of extreme weather events posing a serious threat to coastal residents and their livelihoods, primarily fishermen (Parappurathu et al. 2017). The effects of natural catastrophes on the fishing community, including decreased catch and destruction of infrastructure, equipment, and livelihoods calls for strengthening the risk resilience capacity of fishermen (Punya et al. 2021). Developing an insurance market is critical to imparting resilience to coastal community and managing the risks as outlined in the Sendai Framework for Disaster Risk Reduction (2015–2030) adopted by UN member states (Yaghmaei 2020).

The insurance market for marine fisheries is not well-developed compared to other sub-sectors of agriculture (Van Anrooy et al. 2009; 2022). In this background, the present paper is undertaken with the objectives of: (i) reviewing the status of marine fisheries in India; (ii) investigating the adoption of marine fisheries insurance and the constraints thereupon; and (3) examining the prospects of reforming the marine fisheries insurance in the light of experiences of crop insurance.

Data and methods

The study uses both primary and secondary data. The secondary data were collected from published sources from the Ministry of Fisheries, Animal Husbandry and Dairying of Government of India and Ministry of Fisheries of Government of Kerala. The primary data was collected from marine fishers of Cochin, Kerala, from both the artisanal and mechanised fishers. The Ernakulam district of Kerala was selected purposively as the district contributes significantly to marine fish landings. The district has a fisherfolk population of more than 42000, accounting for 6.9% of the total fishermen in the state, coming from more than 9300 fisherfolk families. The district has several fish landing centres, among which the major ones are Chellanam, Kalamukku, Munambam and Thoppumpady. A snowball sampling method, a non-probability sampling method, is adopted for identifying the respondents. A total of 200 fishers were interviewed—100 practicing traditional fishing and 100 trawl fishing.

Due to the prevailing COVID conditions, the primary data was collected using a mixed method that involved bothdirect personal interview and telephonic interviews. The data pertain to the year 2021–22. To have a deeper insight into marine fisheries insurance, a case study of the Fishermen Welfare Cooperative Development Society at *Njarakkal-Nayarambalam* in Ernakulam was also undertaken. Also, three focused group discussions with fishers were conducted at *Munambam* and Chellanam fish landing centres in Ernakulam.

Our survey schedule included questions on the personal characteristics of the fishermen; their asset status in terms of household's physical assets, financial assets, fishing-related assets; the education status of the fishermen; employment pattern; adoption of insurance; and constraints in adoption of insurance. The constraints in adoption were collected using a 5-point continuum following a Likert type of scale, from "strongly agree" to "strongly disagree", carrying a score of 5 to 1. To arrive at the aggregate score, the individual scores were summed up and the means were calculated.

Results and Discussion

Natural disasters and capture fishery

In the last twenty years (2000–2019), a total of 7,348 catastrophic events have been recorded worldwide, claiming approximately 1.23 million lives, an average of 60000 per year, affecting more than 4 billion people.

However, unlike in previous years, in the last 20 years, the number of deaths has reduced to 0.5 million, affecting 3.9 billion people from a total of 6681 climate events. The disasters have led to economic losses of approximately US$ 2.97 trillion worldwide. India topped the list of those affected in the year 2020, with more than 18 million (CRED & UNDRR 2020).

Fishing communities, the most vulnerable in this group, face the backwash effects of natural disasters. The Tsunami, Ockhi, and Phailin were the major disasters that affected the coastal states of India in recent times. Cyclone Ockhi was a recent hit on the south coast of India. As many as 638 fishermen died while at sea and 344 fishermen who went deep sea fishing before the storm hit were missing. It also caused a huge loss to the livelihood of the coastal community (Table 1). The flood, the severest in a century, affected 60000 ha of agricultural land and caused a loss of Rs 93.7 million to inland fisheries (Chronical 2018).

World fisheries insurance

Globally, the number of people employed in marine fish production during 2010-2018 is estimated at 39 million (FAO 2020a; Van Anrooy et al. 2022). In 2018, fishery insurance accounted for only about 1% of total non-life insurance premiums (Staib et al. 2019; Van Anrooy et al. 2022). The insurance industry has undergone a sea change. With innovations in financial markets and information technology, greater participation in insurance markets is occurring across the globe (Van Anrooy et al. 2022).

Capture fishery insurance

Capture fishing insurance products provide coverage for the protection of vessel (hull), equipment and gear (machinery), as well as for safety and liability (P&I insurance, employer's/crew liability, and general liability) cover. It is uncommon to have insurance for catch loss and income variation (Van Anrooy et al., 2022). In countries such as Chile, Europe (Russian Federation), USA, Oceania, Peru, and most African countries, the fisheries insurance sector is dominated by private entities. In Asia, public insurance, public-private partnerships (PPPs), and cooperative insurance organizations play an important role in providing insurance services to the small-scale fishing industry (Van Anrooy et al. 2022). Micro-insurance has gained popularity in several developing countries of Asia and Africa. Many private insurance companies and international development agencies have entered the field. Another effective strategy in covering risks is the Joint ventures (Tietze 2007; Parappurathu et al. 2017). A micro-credit insurance product that covers various risks including health risks, accidents, risk to household assets from natural disasters is the common form.

Van Anrooy et al. (2022) notes that countries like European countries, Japan, Oceania, the Russian

Table 1 Loss and damage in the fisheries sector

	Assessment				
	Tsunami in Kerala 2004	Phailin in Odisha 2013	Ockhi in Kerala 2017	Ockhi in Tamil Nadu	Ockhi in Lakshadweep
Villages affected (No.)	226	18374	NA	NA	NA
Population affected (lakhs)	10	1.3	NA	NA	NA
Human lives lost (No.)	238	50	350	30	NA
Human missing (No.)	NA	NA	141	203	Nil
Dwelling unit destroyed (No.)	2919		3474	6363	1022
Migration (No. lakhs)	0.025	8	NA	NA	NA
Crop area affected including riverbank near the seashore (Ha)	3989	67000	7817.43	6625	NA
Livestock (No.)	883		Nil	7654	1691
Boats destroyed (No.)	3989	8423	384	4107	37

Source Roshan 2018 and Irshad 2020; Report of Rajya Sabha standing committee 2018.

Federation, and the United States of America have insured a large portion of the semi-industrial fishing fleet. In Europe, an estimated 50,000 fishing vessels were insured. Parappurathu et al (2017) notes that the government-backed Fisheries Mutual Insurance Scheme (FMIS) in Japan as an example of vessel insurance. In this case, the vessel insurance is as high as 81%. In China at least 55,500 vessels are insured. Thus, the country turns out to be the largest market for hull insurance of fishing vessels. However, in Asia, Latin America and Africa, the insurance is not widespread and about 10,000 semi-industrial fishing vessels operate without marine hull insurance. In India, only about 3-4% of the total vessels are insured (Van Anrooy et al. 2022). A demand and supply gap in marine hull insurance persists, which indicates that insurance coverage for fishing vessels is low (FAO 2022). Frequent extreme weather events and limited alternative financial services make marine fisheries insurance unattractive to small scale insurers. For small fishing vessels, third-party liability insurance is mandated by countries like Europe, Asia, and the Americas have mandated (Barange et al. 2018).

Fishery insurance service delivery in India

Presently, 52 insurance companies—24 dealing in life insurance and 28 in non-life insurance—are functioning in India (https://indiancompanies.in/). The government has taken a number of steps to boost the use of insurance products in agriculture. India is the second-largest fish producer in the world, producing 14.7 million tonnes equalling to 7.8% of global fish production. At primary level, this supports the livelihoods of around 16 million people. Vishnoi et al. (2020) notes that over the past three to four decades, the government has strengthened fisheries and aquaculture insurance.

The majority of the capture fishing insurance plans now offered in India provide coverage for “named perils”, while some companies do provide “full risk” coverage. The perils generally covered under capture fishery insurance are (i) natural calamities like cyclones, storms, lightning, tsunamis, earthquakes, floods, etc.; (ii) mishaps resulting from technical or mechanical failure;(iii) accidents due to human error such as stranding, sinking, and collision; (iv) third-party-caused accidents;(v) loss caused by theft, maritime debris, and vandalism; and fire and explosions involved in the fishing sector are generally included. Only certain policy schemes cover risks such as war, acts of hostility, piracy, terrorism, capture, seizure, detention, etc. (Parappurathu et al. 2022).

Accident insurance is a critical product in the case of insurance in capture fishery sector, as it covers the risks of life of active fishermen or disabilities that may occur while engaging in fishing activities. Group accident insurance schemes that cover life and disability risks of boat crew is widely practiced and promoted (Parappurathu et al., 2022). Other than the central and state governments, cooperatives and NGOs are also active in the insurance market, for example, the Kerala State Co-operative Federation for Fisheries Development Limited (Matsyafed) in Kerala, the South Indian Federation of Fishermen Societies (SIFFS) in Kerala and Tamil Nadu, and the Humane Action (DHAN) Foundation in Andhra Pradesh (Parappurathu et al. 2022). For instance, the Group Accident Insurance Scheme run by Matsyafed in Kerala covered the risks of 96704 fishermen in 2019–20 (FAO, 2022). According to a survey conducted by ICAR-CMFRI in 2016, about 80–100% of the fishermen in Kerala were covered by an accident insurance scheme, whereas in Tamil Nadu, it ranged from 16–100%. The insurance coverage is much less in other states (CMFRI 2016).

After the 2004 Tsunami, micro-insurance schemes targeting vulnerable fishermen were piloted in India support from NGOs and self-help groups (SHGs) of fisherfolk, but met with limited success (Parappurathu et al. 2022). A comprehensive insurance programme called the “Post-Tsunami Sustainable Livelihoods Program (PTSLP)” has been running in Tamilnadu since 2017 with support from the International Fund for Agricultural Development (IFAD). The initiative intended to return the thousands of Tsunami victims to a stable and fruitful way of life. Risks including life, health, personal accidents, and fishing assets are covered under this program (IFAD, 2020, https://www.ifad.org/).

The number of vessel insurance products available in India is very few. Only about 3–4 per cent of the country’s fishing fleet has vessel insurance (Van Anrooy et al. 2022). Vessel insurance products vary widely depending on the company that offer it, type of vessel and, the area of operation. The yearly premium typically amounts to 3-5% of the vessel’s worth. Compensation is only given when a vessel sustains

Table 2 Level of adoption of fishery insurance schemes

	Traditional	Trawlers	Total
Life insurance (at present)	9 (9)	20 (20)	29(14.5)
Life insurance (in the past)	5 (5)	8 (8)	13 (6.5)
Vessel insurance (at present)	100 (100)	0	100(50)
Vessel insurance (in the past)	0	0	0
Gear insurance	0	0	0

Note The figure in the bracket indicates the percentage of adoption of the insurance scheme by fishermen

complete damage. Apart from reasonable coverage of marine fishermen risks in the southern Indian states of Kerala and Tamil Nadu, coverage of other risks is limited. The fishermen are reluctant to insure their lives and fishing assets (Parappurathu et al. 2017).

Level of adoption

All the traditional fishers adopt insurance, as it is bundled with credit provided by Matysafed (Table 2). In Kerala, the Matsyafed and the Kerala Fishermen's Welfare Board (KFWFB) offer services in collaboration with public insurance companies. Among the available risk financing services, vessel insurance is the most promising insurance product, and half of the fishermen have insured their vessels against accidents. They are covered under traditional sector. It is worth noting that the provision of gear insurance was minimal. Lack of appropriate fishing gear (fishing nets, lines etc) insurance may be the main reasons. Further, verification of fishing gear damages occurring mostly while fishing is a difficult. The prevalence of life insurance was higher (14.5%). Regarding accident insurance, the 'Group Accidental Insurance Scheme' is the main programme now in operation, which protect the life and disability risks of boat crews, but was not adopted by the sample fishers.

Constraints to adoption of insurance

Poor awareness is one of the main factors that deters fishermen from accessing insurance coverage for themselves and for their assets. Among the active respondents, 44.5% were unaware of available insurance schemes (Table 3). Fishermen perceived a high premium rate (M=4.94) as the main constraint hindering insurance uptake. This was followed by inadequate insurance coverage (M=4.82). No subscription of vessel insurance among trawlers is mainly due to high premiums. Insurance is voluntary for mechanised fishers, including trawl operators. The penetration of insurance is quite low in the sector—the study pointed to the total absence of vessel insurance. The cost of a mechanised fishing vessel ranges between Rs 10–15 million, warranting a high premium. There is a wide-ranging perception that the

Table 3 Major constraints faced by the fishers in marine fisheries insurance

Sl No.	Statements	Traditional		Trawlers		Total	
		Mean score	Rank	Mean score	Rank	Mean score	Rank
1	Lack of suitable insurance products	3.95	6	4.3	7	4.13	6
2	Premium is high	4.94	1	4.93	1	4.94	1
3	The insurance facility is not nearby	3.23	7	4.33	6	3.78	7
4	Procedure for a claim is cumbersome	4.62	5	4.87	2	4.75	3
5	Will not receive claims	4.69	3	4.79	5	4.74	4
6	The claims are inadequate to cover the loss	4.82	2	4.83	3	4.83	2
7	The claims are not paid in time	4.67	4	4.8	4	4.74	5
8	Difficult to understand the terms and conditions	2.83	8	3.09	8	2.96	8

requirement of vessel insurance is coming down due to advancement of information and communication technologies (Krishnan et al., 2022). Fishers perceive that with the advancement of vessel technologies and communication system, regulatory regimes and better prediction of weather, the risk at sea would reduce. Further, fisheries have faith on the resilience of the social system that should any mishap happens, fisheries would undertake mutual help. But the efficacy of the system varies depending on the social settings.

Apart from high premiums, a cumbersome process in claim settlement (M=4.87) and inadequate insurance coverage (M=4.83) were found to dissuade trawlers from insuring. Due to moral hazard and asymmetric information, claim payout is calculated based on a detailed underwriting process. The insured is required to submit a claim form or other documents as evidence of loss. The difficulties in providing proof of the accidents that occur at sea affect the claim settlement. Further, the claim amount is insufficient to cover the loss, warranting a large out-of-pocket expenditure. Inadequate insurance products and options are a constraint. This is especially relevant for the vessel and gear insurance and damage against fishers' assets. The limited subscription, in turn, increases the administrative cost of the insurance service, which pushes up premium rates. On the demand side, small-scale fishers regard the insurance too costly because of the high premium. The sector, therefore, calls for an equitable, affordable, and accessible risk-covering mechanism. The following section discusses various options and strategies for reforming the fishing insurance sector in India.

The Matsyafed provides insurance to traditional fishermen for their life, engine, and vessel. It is mandatory and bundled with credit. Life insurance covers Rs 10 lakhs with a premium amount of less than Rs 500 per year. The total premium is about 4% of loans for engines and 2% of loans for vessels. In the case study of *Njarakkal-Nayrambalam Fishermen Development Welfare Cooperative Society* (FDWCS), out of the total 3850 members affiliated with Matysafed in the year 2022, only about 23% of members availed of life insurance in 2022. The demand for insurance by non-loanee is about 10–15% only. In Kerala, other than the Matsyafed, life insurance coverage for fishermen is offered by the Kerala Fishermen's Welfare Fund Board (KFWFB) also, with a sum assured of Rs10 lakhs for a premium of Rs 100 in a year. The demand for vessel insurance is low, even at subsidised premium; insurance is considered as an additional expenditure rather than a risk mitigating/transferring mechanism. Further, the fisheries anticipate returns for the expenditure incurred on premium. This clearly points to the need for awareness creation (Krishnan et al., 2022).

Learning lessons from the crop insurance

Crop insurance in India is relatively well developed compared to fisheries insurance. There are several learning lessons from crop insurance that can be imbibed for the fishing sector. Lack of transparency and a high level of moral hazard are problems in crop insurance that resonates with the fisheries insurance industry. In the following section, we discuss the options and strategies to reform marine fisheries insurance in light of experience in crop insurance.

In crop insurance, the most relevant schemes are The *Pradhan Mantri Fazal Bima Yojana* (PMFBY) and the *Restructured Weather Based Crop Insurance Scheme* (RWBCIS). The PMFBY provides insurance cover to farmers should any notified crop failure occur due to natural calamities, pests, or diseases (Krishnan et al., 2022). The RWBCIS provides insurance coverage to farmers as against crop damages resulting from adverse weather conditions using weather parameters (Vishnoi et al. 2020). Risk and economic loss in the fishing sector are by-products of weather changes. Marine fishing is climate sensitive, and therefore, insurance plans needed to be sensitive to weather variations. Weather index-based insurance scheme provides options to use the technological development by satellite data and inputs from weather stations to trigger insurance payments in the event of weather-related events, especially in the present context where fishing is firmly related to climate change. Additionally, there is a need for simplifying procedures and eliminating the problems of moral hazard and adverse selection (Parappurathu et al. 2017).

Krishnan et al (2022) provides a gist of learning lessons for marine fisheries that can be imbibed from the experience WBCIS. The WBCIS provides insurance cover in case of variation with respect to rainfall (a) rainy days, unseasonal rainfalls, deficit rainfall, excess rainfall, dry weather, dry days (b) relative humidity;

(c) temperature (high temperature, hailstorm), (d) wind speed, (e) a combination of the above and (f) hail and cloudburst (IRDAI 2022). The insurance contracts are made against specific hazards or evets, for which data is recorded at the local weather stations (Hazell et al., 2010). Such events include local yield loss, drought, cyclone, and flood, to mention a few. The indemnifications are triggered by pre-specified index patterns instead of actual returns, which eliminates on field evaluation requirements. Further, such weather-based insurance provide opportunity for shifting to global markets a part of the risk, as the risk is re-insurable (Hazell et al. 2010; Rajan et al. 2016; Al-Maruf et al. 2021). All the potential buyers in the same area are offered insurance with same premium rate, which makes the insurance scheme regionally based. The granulation of the regional basis can be improved by installing infrastructure like automatic weather stations. Hazell et al., (2010) notes that the various options to structure the pay outs- from a simple zero/one contract (i.e., if the threshold is exceeded, the payout rate is 100%) to a layered payment schedule (Hazell et al. 2010). In marine fisheries too, the risks are co-variate and affects all the fishermen in the regions, the pattern of risk incidence increases with the geographical granulation. Inputs from platforms like Geographical Information System (GIS) and remote sensing can be used to aid weather-based insurance schemes in coastal regions. The platforms can be effectively used to estimate the compensation requirement with regard to various coastal assets like craft, gear, sea cages, aquaculture farms etc. Other advantages include quick claim settlement, no need for documents as proof of loss, and lower transaction costs (Krishnan et al., 2022). The strategy can be replicated for marine fishing as well, as the risks are covariate. A major limitation of marine insurance is the lack of schemes to cover damage to the coastal assets of fishermen. Often, damages to the fishing vessels have devastating effect on the fishermen, as it would be difficult for the affected fishermen to overcome the loss and re-enter the fishing activity. Since the risks (like storm) affects all alike in the affected area, it would be difficult for availing community assistance in terms of capital support. Inclusion of fishing equipment such as vessels and gear under insurance would provide help a number of fishers to re-enter the fishing activity after the disaster. Advanced Vessel Monitoring Systems (VMS) can track fishing vessels and assess incidents such as capsizing and collisions. The insurance companies can use such information to validate the impacted beneficiaries' insurance claims. In addition, mobile applications and information and communication technology (ICT) tools can be leveraged to speed up the processing of insurance claims and provide real-time damage assessment of fishing vessels, mariculture units and fish farms (Molenaar and Tsamenyi 2000; Parappurathu et al. 2017).

One of the basic features of the index-based insurance scheme is that it is linked to credit, and farmers need to get loans (Krishnan et al., 2022). Index insurance for development is also used as collateral security against bank credit. This way, fisher can easily access formal credit lending institution. Weather-based index insurance could serve as an effective, market-mediated solution to effective disaster management. The efficacy of the weather-based insurance schemes can be improved further at practical level by running it on pilot basis in some selected locations, developing incentives linked policies and awareness generation.

Conclusions and implications

This article attempts to provide insight into the current status of fisheries insurance in India, assesses the status of the adoption of fishery insurance mechanisms in the fishing community, and provides an alternative risk-covering mechanism, drawing lessons from crop insurance, particularly from the weather-based crop insurance schemes. The fisheries insurance is not well developed. Traditional vessels and individual life insurance plans have marginal coverage. However, insurance penetration for trawling vessels, gear, and group accidents is minimal or non-existent. The main reasons for the low subscription rate are the lack of concern and the lack of awareness. Factors such as high premiums, inadequate coverage of the loss, and delay in settlement indemnities are identified as reasons for the poor adoption of insurance. A weather index-based insurance scheme is an alternative solution to the problem of marine fishing insurance. One key issue in fishermen's livelihood is income fluctuations, and weather-based insurance can help aid income insurance schemes. However, income insurance scheme is presently not in vogue in India, but appears to be relevant because of sharp weather variability and associated weather warnings that prohibit fishers from venturing out to the seas, affecting their livelihood. However, it will pose operational challenges. In this context, it is relevant to start pilots in weather based (weather index based) marine fishing insurance in some parts of the country. For this, measures such as harnessing the potential of technology and bringing about attitudinal changes through awareness generation are important.

Acknowledgements

The paper forms part of the project titled "Assessing Input and Service Delivery System in Marine Fisheries Development in India", carried out at ICAR- Central Institute of Fisheries Technology (ICAR-CIFT), Kochi. The authors are thankful to Dr A.K. Mohanty and Dr Sajesh V.K., Head and Senior Scientist, respectively, ICAR-CIFT, Kochi for their suggestions and useful discussions. The authors are thankful to Mr. K.D. Jos, Mr. Subhash Chandran Nair and Ms Tessy Francis, technical officers of ICAR-CIFT for their contribution towards data collection. Thanks are also due to Ms Nimitha Paul and Ms Anusha who contributed to data collection and processing.

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Received 8 January 2023 Accepted 25 May 2023

Agricultural Economics Research Review 2023, 36 (1), 53-64
DOI: 10.5958/0974-0279.2023.00004.6

Sexed semen technology for cattle breeding: an interpretative review on its performance, and implications for India's dairy economy

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Abstract Sexed semen is an innovative biotechnological tool for improving the production efficiency, reproductive performance and economics of dairy farms. Despite these benefits, the adoption of sex semen is limited to the commercial dairy herds. Several factors such as its low conception rate and high cost restrict its applicability in smallholder dairy production systems. Further improvement in the technology can narrow don the fertility gaps between the sexed semen and conventional AI, leading to an improvements in adoption and profitability. Rising demand for milk and declining utility of male cattle in India reinforces the need for the adoption of sexed semen technology.

Keywords Sexed semen, performance, implications, India

JEL codes Q22, Q18, C5

Introduction

In the past five decades, India's milk production has increased rapidly, making the country self-sufficient in milk and milk products. Now, milk with a share of about 19% in the gross value of output of the agricultural sector is the largest agricultural commodity. The per capita milk availability has improved from 107 g/day in 1970-71 to 444g/day in 2021-22, almost 36% more than its recommended dietary allowance of 300g/day (GoI 2022). This remarkable progress in the dairy sector is termed as 'White Revolution', and in the development literature it is as celebrated as 'Green Revolution'.

The tremendous growth in milk production happened due to several technological and institutional interventions. Towards the late 1960s, India started developing a network of village-level dairy cooperatives to link producers to urban demand centres. The number of village dairy cooperatives increased from 13284 in 1980-81 to 228374 in 2020-21, and the milk procured by them from 0.93 million tonne to 21.42 million tonne (NDDB 2022). Further, as a part of the economic reforms process initiated in 1991, the dairy industry was opened for the private investment. The private processors now procure as much milk as do the dairy cooperatives. Besides, significant investments have been made in veterinary infrastructure and human resources (Kathayat et al. 2021). In 2020-21, there were a total 65828 veterinary institutions (i.e., hospitals, polyclinics and dispensaries), up from 54631 in 1999-2000.

Simultaneously, efforts were made for genetic enhancement of indigenous cows through artificial insemination using the semen of high-producing exotic cattle. The share of in-milk crossbreds in the total in-milk cows has increased from 17 % in 1990-91 to

38.3% in 2021-22, and their share in the total cow milk production from 33.5% to 61.2% (GoI 2022).

Over the last three decades, cattle population has shifted significantly towards rearing more of females. Their number increased from 102.98 million in 1992 to 145.12 million in 2017, while the population of male cattle declined from 101.59 million to 47.4 million (GoI). Farmers desire to have more females to meet the rising demand for milk, expand their herd size, and improve profitability (Boustan et al. 2014; Murphy et al. 2016; Holden and Butler 2018; Verma et al. 2020). Breeding is one of the ways to attain these goals. Animal breeding technologies have evolved from natural breeding to Artificial Insemination (AI), embryo transfer/IVF, and sexed semen (Vishwanath 2003; Rodriguez-Martinez 2012; Khanal and Gillespie 2013). These technologies have been instrumental in improving breeding efficiency, reproductive management and economics of farms (Heikkilä and Peippo 2012; Ribeiro et al. 2012). Hence, there is strong need to adopt and exploit the potential of such technologies.

Sexed semen is the latest biotechnological tool, which can be utilized to produce animal of the desired sex with high accuracy. It has the potential to improve the farm profitability by producing more females for milk production. However, the recommendation to adopt this breeding invention should not be entirely based on biological factors; its economics must be considered. Several studies have been published on sexed semen breeding technology emphasizing on its technical aspects (DeJarnette et al. 2009; Rodriguez-Martinez 2012; Rath et al. 2013) and reproductive outcomes (Sá Filho et al. 2018; Vishwanath and Moreno 2018; Reese et al. 2021; Zuidema et al. 2021). This study is an attempt to summarize the recent literature on sexed semen technology emphasizing its utility, adoption, performance, and profitability.

Utility of sexed semen

Artificial insemination (AI) has been the most successful breeding technique in accelerating genetic gains, increasing productivity and reducing diseases of livestock (Zuidema et al. 2021; Upadhyay et al. 2022). Breeding methods evolved consistently over time and currently AI with sexed semen is gaining popularity. Sexed semen is the latest cattle breeding technology developed in 1980, which can be used to produce calf or heifer with 90 percent accuracy (Rath et al. 2013; Seidel 2014; Butler et al. 2014). AI through conventional semen breeds 51 percent male calves, lowering the economic value and profitability of dairy farm (Karakaya et al. 2014; Guner et al. 2020). This favours the use of sexed semen (Ghavi Hossein-Zadeh et al. 2010). This technology is well-identified for commercialisation (Garner and Seidel 2008; Rath et al. 2013) and is reported to account for 9 percent of total breeding efforts globally (Sharma et al. 2019), but significantly varying across countries. Sexed semen offers several benefits, in term of desired sex, increased heifer supply, herd expansion, replacement of cows, reduced cases of dystocia, genetic gain and biosecurity of herds (Fetrow et al. 2007; De Vries et al. 2008a; Seidel 2014; Ettema et al. 2017; Cottle et al. 2018). Despite these advantages, sexed semen adoption in developing countries remains low due to its lower fertility and high cost in comparison to the conventional AI (Rodriguez-Martinez 2012; Holden and Butler 2018; Neculai-Valeanu and Ariton 2021). However, continuous efforts to optimize the techniques of sorting sexed semen has enhanced the accuracy to produce offspring of desired sex (Seidel 2003; McCullock et al. 2013).

Factors affect adoption of sexed semen

Rising demand for animal products necessitates the requirement to harness the potential of modern breeding technologies. Adoption of breeding technologies can generate high returns for dairy enterprises (Gillespie et al. 2014). The early uptake of innovative technologies is influenced by their own characteristics, and the socioeconomic and institutional factors (Olynk and Wolf 2007; Telford et al. 2015).

AI has been instrumental in enhancing genetic gains and milk yield during the past seven decades (Rath et al. 2013). Adoption of AI at farm level is positively influenced by education of owner, herd size, information access and knowledge regarding AI (Ghosh et al. 2005). While, the lack of AI centres and low conception rate force farmers to rely on natural breeding (Rathod et al. 2017). Along with this, the cost of AI service, and distance to service provider negatively impacts its adoption. However, higher returns positively influence its adoption (Howley et al. 2012). In developing countries, the literature also emphasizes the role of institutions and infrastructure in accelerating the adoption of modern breeding technologies (Mugisha et al. 2014; Mwanga et al. 2019). Public extension system can be instrumental in delivering quality breeding services (David et al. 2018; Verma et al. 2020).

Sex sorted semen has gained popularity due to its several advantages over conventional semen, but its uptake has been limited (Amann 1999). Early adopters of this technology are farmers who possess higher education, have specialised knowledge in dairying, and maintain large herds with good reproduction management (De Vries et al. 2008a; Khanal and Gillespie 2013).

Commercial uptake of sex semen requires attention on several aspects related to market, management and environment (McCullock et al. 2013). The cost per straw, value of animal produced, gross returns and financial position of dairy farms are important economic factors influencing adoption of any breeding technology (Olynk and Wolf 2007). The higher price of sexed semen, which is three to five times more than of the normal semen, restricts its wide scale application (Norman et al. 2010; Balzani et al. 2021). Contrarily, the relatively higher utility of females and heifers can overcome the extra cost associated with sexed semen. Furthermore, for successful adoption of sexed semen, several researchers have emphasized more on management factors such as conception rate and sex ratio (McCullock et al. 2013;Telford et al. 2015). Producers with high conception rates in their dairy farms are more likely to adopt sexed semen in their breeding programme (De Vries et al. 2008a). Till date, many a studies have reported that sexed semen has lower conception rate in comparison to normal semen (Healy et al. 2013; Seidel 2014; Pahmeyer and Britz 2020). Hence, the conception rate through sexed semen becomes a critical factor in farmers' choice of breeding technology.

Reproductive performance of sexed semen

Good reproductive performance is an essential element in ensuring farm profitability of a dairy enterprise (Howley et al. 2012). In field trials, several studies have investigated reproductive outcomes of sexed semen. For evaluating sexed semen performance, these assessed conception rate, sex ratio, dystocia cases, calf mortality and compared these parameters with the normal semen AI. Chebel et al. (2010) reported that the conception rates obtained through sexed semen are lower than that realized through conventional semen. Lower pregnancy in the case of sexed semen is attributed to low sperm concentration and reduced fertility during the sorting process (DeJarnette et al. 2008; De Vries 2010).

Table 1 presents a summary of the studies reporting on conception rates and sex ratios achieved using the sexed and conventional semen. Using data on conception rates from multiple studies, we estimated mean values and range of conception rate in cows and heifers for sexed and conventional semen separately. For cows, the conception rate is with sex sorted semen is significantly lower (40.8 %) compared to that with the normal semen (52.35%). The conception rate from the sexed semen ranges between 25 and 51 percent, whereas it is 30 to 62 percent in the case of conventional AI. In the case of heifers, the conception rate is 44.35 percent (32-56%) for sex sorted semen and 59.03 percent (40-70%) for conventional seme. By comparing the conception rates of sexed semen in heifers and cows, significant gaps in conception are observed. Therefore, keeping the economics of dairy farm in perspective it is advised to use sexed semen in heifers than in cows (Fetrow et al. 2007; De Vries and Nebel 2009; DeJarnette et al. 2009).

Several claims have been made regarding narrowing down the fertility gap between sexed and conventional AI through optimization of sex sorting procedures (Lenz et al. 2016) but the gap has never been bridged and still persists in heifers and lactating cows (Norman et al. 2010; Seidel 2014). We analysed 22 studies published during last decade on conception rates in heifers. These reveal that fertility gap continues to exist between the sexed and the conventional semen (Figure 1). There is also a wide variation in fertility gaps across studies.

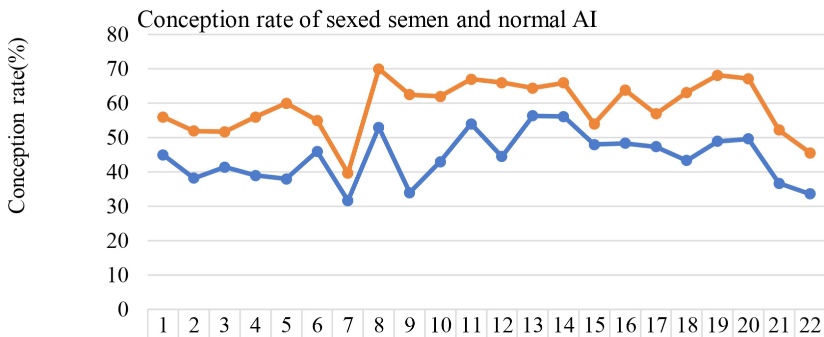
Second parameter used to assess the reproductive outcome of sexed semen is the sex ratio. It represents the probability of producing an animal (male or female). In case of conventional semen AI, the chances of having male and female animal are generally 50:50.

However, with the sexed semen AI the sex ratio of producing animal of desired sex is reported to be as high as 90 percent. (Norman et al. 2010; Healy et al.

Table 1 Reproductive efficiency of sexed semen versus conventional AI

Authors	Country	Animal	Conception rate (%)		Sex ratio (%)	
			SS	AI	SS	AI
Chebel et al. 2010	USA	Holstein heifers				
		Herd A	38.2 (123)	51.9(104)	85.7	47.7
		Herd B	41.4 (220)	51.7(924)		
Norman et al. 2010	USA	Holstein cows	25	30	85.1	45.4
		Heifers	39	56	90.2	50.5
DeJarnette et al. 2011						
DeJarnette et al. 2009	USA	Holstein heifers	38 (2319)	60 (2292)	–	–
	USA	Holstein heifers	45 (39763)	56 (53718)	89	50
Sá Filho et al. 2012	Brazil	*Bos indicus*	46 (246)	55 (245)	–	–
Healy et al. 2013	Australia	Holstein heifers (4456)	31.6	39.6	86	48
Hutchinson et al. 2013	Ireland	Heifer	53	70	–	–
Abdalla 2014	Egypt	Holstein heifers	34 (426)	62.5 (325)	89.6	50
Cooke et al. 2014	USA	Cows (Angus * Herford)	34.9 (149/439)	56.0 (252/454)	91.3 (136/149)	57.2 (144/252)
Karakaya et al. 2014	Turkey	Holstein cows	31.8 (47/148)	40.9 (63/154)	–	–
Seidel 2014	USA	Holstein heifer	43 (288)	62 (263)	–	–
		Anguis heifer	54 (123)	67 (126)		
		Cows	55 (42)	71 (21)		
Remmik et al. 2016	Estonia	Holstein heifers	44.5	66.0	93.0	49.3
			56.3	64.4	93.0	48.7
			56.1	65.9	93.0	48.8
Holden et al. 2017	Ireland	Holstein cows and heifers	48 (1486)	54 (39366)	–	–
Joezy-Shekalgorabi et al. 2017	Iran	Holstein heifers	48.3	63.8	91.1	51.3
Crites et al. 2018	USA	Cow (Crossbred)	49.2 (95/193)	56.7 (114/201)	–	–
Jethva and Patel 2018	India	Holstein heifers	39.53	–	86.15	–
Sharma et al. 2018	India	Jersey cows	40 (70)	49.32 (148)	82.14	50.68
Oikawa et al. 2019	Japan	Heifers	47.3 (45465)	56.9 (41857)		
Chebel and Cunha 2020	USA	Holstein heifers	43.3	63.1	65.8	40.5
Drake et al. 2020	Ireland	Holstein cows, Jersey	51 (1142)	62 (722)	–	–
Guner et al. 2021	Turkey	Holstein Heifer	48.9	68.1	89.8	51.6
Joshi et al. 2021	India	HF, Jersey cow	39.92	–	90.98	–
Zargaran et al. 2021	Iran	Holstein heifers				
		Insemination I	49.58	67.1	–	–
		Insemination II	36.67	52.2		
		Insemination III	33.64	45.56		
Shinde et al. 2022	India	Gir Cows	40	50	75	60

Figure in parenthesis represents cow and heifer number in different studies



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Heifers CR (SS)	45	38	41	39	38	46	32	53	34	43	54	45	56	56	48	48	47	43	49	50	37	34
Heifers CR (AI)	56	52	52	56	60	55	40	70	63	62	67	66	64	66	54	64	57	63	68	67	52	46

Figure 1 Summary of conception rates achieved in various trials using sex semen (SS) and (AI) in heifers

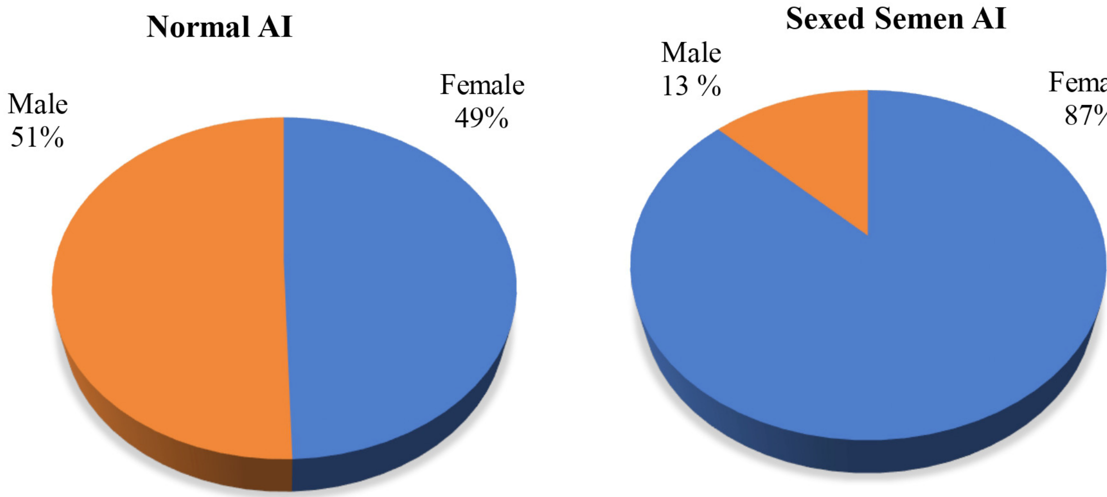


Figure 2 Desired sex ratio in case of sexed versus normal AI in heifers and cow

2013; Joezy-Shekalgorabi et al. 2017; Guner et al. 2021; Zargaran et al. 2021). When sex sorted semen is used, the accuracy to produce animal of desired sex is significantly higher (87 %) than that of conventional AI (49%) (Figure 2) and this accuracy rate does not vary with the animal type i.e., heifer or cow.

Profitability of sexed semen

Sexed semen has been commercially available to producers and its use has increased in recent years (Cottle et al. 2018). Given the fact that it has higher cost as compared to normal AI, reproductive (conception rate and sex ratio) and economic outcome must be considered before recommending this technology to dairy producers (Boustan et al. 2014). Economic assessment of sexed semen technology is quite complex due to interaction between technical (conception rate), market (price) and outcome (desired sex) aspects (Seidel 2003). Researchers have attempted to evaluate the economics of sexed semen from different angles; cost of female produced, additional milk sale, heifer sale, beef production, Net Present Value (NPV), genetic gains, lifetime economic gain, per lactation gains, etc. Various tools like bioeconomic models, stochastic modelling, budgetary analysis, linear programming tools and simulation approaches have been attempted to assess the gains (Cabrera 2009; McCullock et al. 2013; Pahmeyer and Britz 2020; Cabrera 2021).

Economic evaluation through budgetary analysis involves additional cost and returns. Additional cost includes the cost of decreased conception and higher price of sexed semen; while additional revenue is from more female calf and milk production (Butler et al.

2014). In addition to conception rate (CR) and semen cost, other factors like sex ratio, relative value of animals, dystocia cost and biosecurity also affect economic value of sexed semen. Furthermore, researcher evaluated economics of sexed semen by incorporating genetic gains through various simulation modelling approaches, which are more comprehensive in evaluating the total gains (Fetrow et al. 2007; Ghavi Hossein-Zadeh et al. 2010; Lavaf et al. 2013; Ettema et al. 2017).

Conception rates and economic value of sexed semen

In economic evaluation of sexed semen, the critical factor which influences the economic outcome is conception rate (RCR) in comparison to conventional AI. Economic values from sexed semen program have positive relationship with conception rate (CR). With low CR (34% of normal AI) only one service in heifers is recommended, while for high CR (83% of normal AI), the returns are positive for all 5 services (Cabrera 2009). Profit per heifer is reported to have increased by US$91 for RCR (Relative Conception Rate) of 0.80, by US$73 for RCR of 0.75, and by US$57 for RCR of 0.70 (Boustan et al. 2014). Cumulative discounted profit (US$/cow) over 10 years increased from 5550.7 to 6142.8 with increase in conception rate from 35 to 55 precent. (Lavaf et al. 2013). In addition to this, sensitivity analysis reveals that market value of female calves and conception rate are major factors which impact economic values (Remmik et al. 2016). Improvement in herd reproductive performance from medium (20% CR) to high level (30% CR) increases income three-fold (Cabrera 2021). Hence, herd with good reproductive management level benefit more from this technology (Ettema et al. 2017).

Economic value of sexed semen without genetic gain

Economic value of sexed semen through partial budgeting approach focuses on additional heifers produced, income from more heifers, reduction in cost of producing female animal and additional AI expenditure due to lower conception rate. Seidel (2003) calculated "break even" premium which could be afforded for sex semen given the higher relative value of the desired animal. Sexed semen with 54 percent pregnancy rate, 5.1 extra doses can be purchased per female to produce desired animal. Another measure is the value of desired calf, that must be higher than that of less desired one by $200 at 60 percent conception in heifers.

Uptake of any new breeding technique is associated with higher direct cost of production. The cost of AI with sexed semen has been reported 40 percent higher than that of normal AI (Ribeiro et al. 2012). Weigel (2004) estimated farm expenditure to increase by US$47 to US$56 when semen price is US$50. Breeding expenditure of modern breeding services is although higher, but cost of producing female is less and the economic returns are higher from sexed semen in the first lactation (Chebel et al. 2010). From AI to calving, the rearing cost of sexed semen heifers has been estimated higher (US$771.9) than conventional (US$759.1) due to low conception rate. Osada (2019) reported that it is relatively cheaper to produce a female using sexed semen.

Returns on assets are higher when sexed semen is used (Cottle et al. 2018). Increase in profit have been more from sexed semen than crossbreeding (Pahmeyer and Britz 2020). Farms incorporating adopting embryo transfer (ET) with SS tend to have higher gross returns (Heikkilä and Peippo 2012). Milk production of dairy farms that adopted AI, ET/SS has been reported higher (Khanal and Gillespie 2013).

Net present value of sexed semen and AI breeding

Economic evaluation of normal AI and sexed semen AI through Net Present Value (NPV) represent a fair comparison based on discounted costs and returns over time rather than focussing on one or two services. Cabrera (2009) found that breeding all heifers and cows with sexed semen yield higher return than that of conventional AI. In addition, expected NPV for virgin heifer has been found higher by U$50-70 per head than the lactating cows (Barrientos-blanco et al. 2018). However, Olynk and Wolf (2007) found that the expected Net Present Value (NPV) of conventional AI insemination strategy is better than sexed semen until the latter achieves 86 percent relative conception rate. Furthermore, Remmik et al.(2016) also reported negative net value from sex semen breeding.

Whenever the expansion of dairy farm is considered, sexed semen is a suitable strategy which generate higher profits. Hutchinson et al. (2013) reported that TDNP (Total Discounted Net Profits) of fresh sexed semen is higher than that of sex frozen and conventional semen for a dairy farm of 150 cows. The TDNP increases with expansion of dairy farm. Similarly, Butler et al. (2014), reported that farm expansion (150 cows) with sexed semen yield higher discounted profits (• 491676) than normal AI (• 458106). The difference between net discounted profits further rises with expansion of farm size and longer use of sex semen (Ghavi Hossein-Zadeh et al. 2010; Holden and Butler 2018).

Economic value of sexed semen with genetic gain

If dairy farms using sexed semen pay attention towards the cow selection for replacement, it can enhance genetic gain from both cow as well as bull. Consideration of genetic gains in economic evaluations of sexed semen further justify its uptake. Estimates of the genetic gains from sexed semen varies widely (De Vries et al. 2008a; Weigel 2004) Profit per heifers rises two-fold (US$35 to US$72) when the genetic gains are included in evaluation (Fetrow et al. 2007). De Vries (2008b), in his study reported that due to consideration of genetic gain (US$32) the sexed semen use turns out to be profitable in heifers (US$22). In comparison to conventional AI, rate of genetic gain will be higher through sexed semen breeding strategy (Ghavi Hossein-Zadeh et al. 2010). Boustan et al. (2014) estimated genetic gains of sexed semen through additional milk yield ranging between 89.31 to 135.61 kg.

Relevance of sexed semen to India's dairy sector

Livestock reduces poverty and enhances nutritional security (Birthal and Taneja 2012; Bijla 2018). India owns world's largest livestock and possess significant opportunities for future growth of dairy production and processing (Birthal 2008; Thakur et al. 2021a). However, the low productivity, poor quality, fodder insecurity, and rising unproductive animal numbers are concerns (Birthal and Jha 2005; Kumar et al. 2013; Thakur et al. 2021b; Sharma et al. 2020).

Stray cattle issue: Rising population of stray cattle requires attention. Lower economic value, stringent cattle slaughtering rules, lesser draught power usage, scarcity of feed and fodder have pushed the abandoning of male animals (Natarajan et al. 2016; Guner et al. 2020; Joshi et al. 2021). They forage on garbage dumps which compromises their health and well-being (Balzani et al. 2021). These animals are often involved in road accidents creating potential public health risks.

To deal with surplus unproductive animals, policymakers are suggesting adoption of sexed semen. In medium to long run,the use of sexed semen AI can optimize the population of livestock. However, livestock are concentrated on small and marginal farmers which are resource-constrained to adopt this technology due to additional investment requirements.

Heifer supply and milk production: Once the sexed semen AI is adopted on a large scale, heifer supply will increase. This will satisfy the demand for replacement animal. Further, this will boost milk production, which will reduce prices of milk and milk products. Although, this impact will be gradual due to constraints on its adoption.

Impact on environment: Adoption of sexed semen AI may have two possible impacts on the environment. First, with selective breeding, livestock population can be optimized. This will reduce the total greenhouse gas emission from livestock.

Second possible impact will be on the animal energy availability to agriculture. Animals are a renewable and sustainable source of energy for agriculture operations, reduces the dependence on fossil fuels. However, farm machinery has substituted draught power usage. With the adoption of sexed semen AI, less animal energy will be available and mechanization will further rise. This might increase the fossil fuel consumption and greenhouse gas emission from agriculture.

Conclusion

Sexed semen provides numerous advantages through reducing unwanted surplus male calves, accelerating genetic gain, herd expansion, milk supply, less replacement cost and maintain biosecurity of dairy herd. The key criterion for its successful adoption is the improvement in the conception rate to close down the fertility gap with conventional AI. With improvement in fertility rates, sexed semen ensures to deliver higher economic value to dairy producers than conventional AI. Simultaneously it can resolve the societal and animal welfare concerns highlighted by increasing proportion of unproductive animals. The utility of sex semen must be harnessed to enhance production efficiency, ensuring animal product demand which is socially, economically, and environmentally sustainable through this technology.

In India, this technology has been adopted sporadically, mainly Punjab, Haryana, Uttarakhand and Maharashtra, but its wider adoption is still limited due to low conception rate and higher cost (Kumar et al. 2016). Subsidizing the sexed semen AI and setting domestic production units will help its wider uptake. Limited field studies have reported 40 percent conception rate and 85-90 percent of accuracy in calf/heifer born (Kumar et al. 2016; Jethva and Patel 2018; Sharma et al. 2019; Joshi et al. 2021). However, in the current scenario, using sex semen in heifers and early lactating cows is more profitable.

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Received 10 February 2023 Accepted 31 May 2023

Agricultural Economics Research Review 2023, 36 (1), 65-75
DOI: 10.5958/0974-0279.2023.00005.8

Agricultural exports, agricultural imports and economic growth: evidence from China

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Abstract China's agricultural exports have been growing rapidly. This paper aims to answer the question whether agricultural trade promotes economic growth. Our findings show that domestic investment and agricultural exports have a positive impact on long-term economic growth. However, agricultural imports had a significant negative impact on economic growth.

Keywords Agricultural trade, economic growth, ARDL bounds testing

JEL codes F11, F14, O47, O53, Q17, Q18

Globalization is considered as an ambiguous weapon, leading to positive as well negative outcomes on the economies depending on their techno-economic status, natural resource endowments, and domestic policies (Carter et al. 1996, Estrades and Terra 2012). Several studies have uncovered that trade openness contributes to the expansion of an economy through facilitating technology transfers and spillovers (Tiba et al. 2015,Tiba and Frikha 2018). The link between economic progress and exports is structured around the primary assumption that increase in export ends up leading to growth in economic activity. Increase in exports leads to specialization, higher productivity and scale economies.. Also, the increase in exports helps domestic capital formation.

In the past two decades, China's exports of agricultural products have increased significantly. Its agricultural growth has also improved considerably. This paper examines whether agricultural exports promote Chinese economic growth.

Agriculture trade and economic growth

The implications of trade for economic growth remain an area of debate in theoretical and empirical research. In fact, several economists have theoretically shown the favorable effect of trade on economic growth (Michaely 1977, Balassa 1978, 1989, 1995, Tyler 1981, Grossman and Helpman 1989. In contrast, there is another set of studies that have shown adverse effects of trade on economic growth (Helleiner 1986, Ahmad and Kwan 1991).

Bakari and Mabrouki (2016) examined the nexus between trade and economic growth for Turkey and found trade having a positive effect on economic growth. Likewise for Japan too Bakari (2017) found domestic investment and exports positively affecting the economic growth, but not the imports. Also for Panama, Bakari and Mabrouki (2017a) found a positive relationship between trade and economic growth. In African countries, Bakari (2021) observed a a positive bidirectional causality between exports and economic growth in the long-run as well as short run. For the USA, Bakari and Tiba (2019) found exports to have a positive effect on economic growth in the long run, and imports a negative effect. However, exports are also found to reduce economic growth but imports to have a positive effect in Tunisia (Bakari et al. 2021). For Algeria too, Bakari (2018) observed the similar results. For Urugay, Bakari et al. (2019) found no relations between trade and economic growth in the long run.

It is striking that the relationship between agricultural trade to economic growth has been somewhat remained under-researched. Sanjuàn-Lopez and Dawson (2010) examined the impact of agricultural exports on economic growth in 42 developing countries and found agricultural exports having a positive effect on economic growth. Faridi (2012) studied the nexus between agricultural exports and economic growth in Pakistan and found not significant relationship between the two. Forgha and Aquilas (2015) investigated the relationship between agricultural exports and economic growth in Cameroon and found that agricultural exports have no effect on economic growth in the short-run, but a positive effect in the long-run. For Tanzania, lam and Myovella (2016) found agricultural exports have a positive impact on economic growth. Bakari (2016) too reported similar evidence for South Africa. On the other hand, Toyin (2016) no significant relationship between agricultural exports and economic growth. Simasiku and Sheefeni (2017) inspected the nexus between agricultural exports and economic growth in Namibia, and found no insignificant relationship between the two. Bakari and Mabrouki (2017b) studied the effect of agricultural exports on the economic growth for the South-East European economies and reported that agricultural exports have a positive impact on economic growth. For Pakistan, Mahmood and Munir (2017) a positive and insignificant association between agricultural exports and economic growth. In the case of Egypt, Ahmed and Sallam (2018) examined the long-run and short-run relationship between agricultural exports and economic growth and found a positive relationship between the two. For Nigeria, Busari et al. (2022) too found that agricultural exports positively affect economic growth.

Yifru (2015) analysed the impact of agricultural commodity exports on economic growth in Ethiopia, and reported exports of coffee oilseeds to have a positive and significant impact on economic growth, but not the pulses. Bakari (2017a) found a positive effect of exports of vegetables, and olive oil on economic growth in Tunisia, but not the exports of citrus. In Ghana, Siaw et al. (2018) found cocoa exports causing economic growth, but not the exports of pineapple and banana.

Data and method

The study uses data from 1984 to 2017 from the World Bank database (World Development Indicators, WDI 2018). The data includes GDP (in constant 2010 US$), gross fixed capital formation (in constant 2010 US$), agricultural exports (in constant 2010 US$), and agricultural imports (in constant 2010 US$).

The aggregated form of the empirical equation is:

$$Y_t = f\,(K_t AX_t AM_t) \qquad (1)$$

Where, Y represents GDP, AX and AM respectively represent the agricultural exports and imports.

The data series are converted into logarithms to get the direct elasticities.

$$LogY_t = C_0 + \beta_1 LogK_t + \beta_2 LogAX_t + \beta_3 LogAM_t + \varepsilon_t \qquad (2)$$

As specified by Pesaran et al., (2001), the ARDL bounds testing approach may be realized in three stages. The initial stage is to estimate Eq. (2) by ordinary least squares to know the existence of a long-run relationship among the variables. The F-test for the joint significance of the coefficients of the lagged level variables points no cointegration relationship between them. Hence, Eq. (2) is re-written as:

$$\Delta Log\ Y_{(t)} = C + \Sigma_{i=1}^{m}\ \beta_{1i}\Delta LogY_{(t-i)} + \beta_{2i}\Delta LogK_{(t-i)} + \beta_{3i}\Delta LogAX_{(t-i)} + \beta_{4i}\Delta LogAM_{(t-i)} + \delta_1\ Log\ K_{(t-1)} + \delta_2\ Log\ AX_{(t-1)} + \delta_3\ Log\ AM_{(t-1)} + \varepsilon_t \qquad (3)$$

Where, Log is the natural logarithm, " indicates the variable in the first difference, Y is the variable referring to the real gross domestic product, K is the variable referring to the gross fixed capital formation, AX is agricultural exports, AM is agricultural imports, C is an intercept, t refers to the time, and ε_t is a white – noise error term. Lags (m,n,o,p) are determined using the VAR optimal model, which means that the lag minimizes the Akaike (AIC), Schwarz (SIC), and Hannan-Quinn (HIC) information criteria.

Eq. (3) has been estimated to see the cointegration among variables. Indeed, the cointegration test is rooted predominately on the Fisher test (F-stat) for the joint significance of the coefficients of the lagged level variables, i.e., H0: $\delta_1 = \delta_2 = \delta_3 = 0$, which indicates no integration. After assimilating the F-stat value with asymptotic critical value bounds suggested by Pesaran

Table 1 Tests for Units Roots

	ADF		PP	
	C	CT	C	CT
Log (Y)	0.553793	3.140932	1.210406	1.724755
	2.944346	2.934072	2.969580	2.956315
Log (K)	2.000200	2.563393	0.800249	1.721702
	3.602577	3.548965	3.349277	3.249131
Log (AX)	1.680767	2.499199	2.767064	2.320106
	5.161190	5.493414	5.169945	5.720202
Log (AM)	0.411143	5.009256	0.277028	2.787715
	5.319606	5.308762	6.160105	5.771966

Note ***, **, * denote significances at 1%, 5% and 10% levels, respectively; ( ) denotes stationarity in level; [ ] denotes stationarity in first difference; 'C' denotes Constant; 'CT' denotes Constant and Trend

et al. (2001), the null hypothesis of no cointegration is rejected when the value of the F test surpasses the upper critical bounds value, inculpating that there is a cointegration relationship between the studied variables.

When the null hypothesis of no cointegration is rejected, and cointegration is scheduled, in the second stage the conditional ARDL long-run model that assumes the long-run dynamic where the orders of the ARDL (m, n, o, p) model are chosen by employing AIC. Finally, the end-stage attempts to esteem the error correction model for the short-run by involving the ordinary least squares technique and the AIC to choose the order of the ARDL (n, m, o, p). Diagnostic tests and stability tests are also painstaking to experiment with the quality of suitable for the ARDL model.

Besides, to prove the modality of our estimated model and the lustiness of our estimation, we will estimate diagnostic tests such as Heteroskedasticity Tests, Breusch-Godfrey Serial Correlation LM test, the test of Normality, R-squared, Adjusted R-squared, and Durbin-Watson test. Finally, we will employ a cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ) tests to assay the stability of the residuals.

Results and discussion

Before we maintained with the ARDL bounds test, we put to test for the stationarity status of the picked time-series data to plot their order of integration. This is to keep that the variables should not be stationary at an order of I(2) because the computed F-statistics assuming by Pesaran et al. (2001) are applicable only when the variables are I(0) or I(1).

The Augmented Dickey-Fuller (ADF) test[1] and the Phillips and Perron (PP) test[2] methods are normally common to the unit root test adopted by many researchers, so the same methods were followed in this study.

The results of the unit-roots tests are reported in Table 1 and indicate that all the variables of interest are integrated of order one or I(1) except Log(AM) is integrated of order I(0) and I (1). The ARDL bounds test is then applied to the model.

The bound test was performed to verify the existence of a long-term relationship between the variables by performing an F-test to determine the joint significance of the coefficients of the shifted levels of the variables. The null hypothesis of no cointegration will be rejected if the computed F statistic is greater than the critical value of the upper bound. If the calculated F statistic is less than the critical value of the lower limit, we cannot reject the null of no cointegration. Finally, the result is not conclusive if the calculated F statistic is between the critical values of the lower and upper limits.

Table 2 reports the results of calculated F-statistics. The bound test confirms the existence of a long-run

[1]Augmented Dickey Fuller test, See: Dickey and Fuller (1979, 1981)
[2]Phillips–Perron test, See: Phillips and Perron(1988)

Table 2 ARDL Bounds Test

ARDL Bounds Test		
Test Statistic	Value	K
F-statistic	7.524547	3
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10%	2.72	3.77
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

relation. So the ARDL Model can be returned. For the determination of the number of delays, we adopt the criterion of Akaike Information Criteria (AIC).

Fig. 1 shows the best 20 models according to the Akaike Information Criteria (AIC). The number of delays for China is (3, 4, 2, 4).

According to Banerjee et al (1998), the statistical significance of lagged error term i.e., ECT_{t-1} is further substantiation of the existence of a constant long-run relationship between the series. The statistically significant estimate of lagged error term i.e., ECT_{t-1} with negative sign corroborates our established long-run relationship between domestic investment, agricultural exports, agricultural imports, and economic growth.

The empirical proof announced in Table 3, which pointed out that the coefficient of ECT_{t-1} is -1.107886 which is statistically significant at a 1 percent level of significance (With a P-value equal to 0.0011). In this case, we can say that the equilibrium cointegration equation is significant and that there is has a long-term relationship between the variables.

The long-run analysis is reported in Table 3. Our empirical evidence indicates that domestic investment and agricultural exports have a positive effect on economic growth, and it is statistically significant at a 1 percent level of significance. The impact of agricultural imports is negative and statistically significant at a 1 percent level of significance.

If we find evidence of a long-run relationship between domestic investment, agricultural exports, agricultural imports, and economic growth, then we estimate the

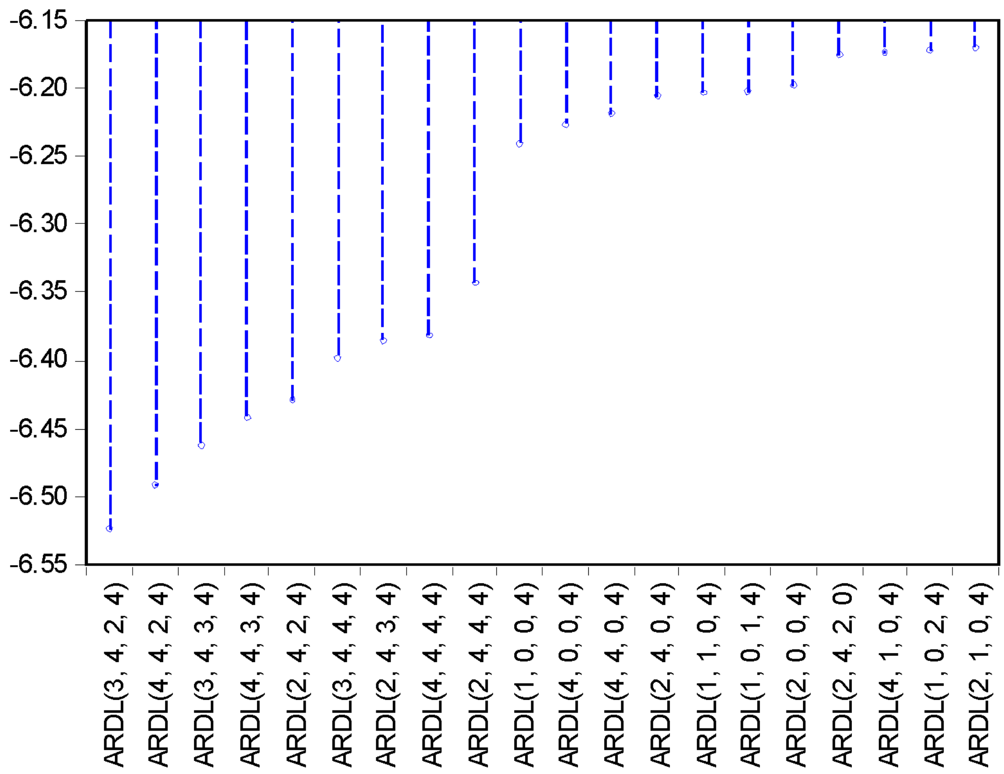

Figure 1 Akaike Information Criteria (top 20 models)

Table 3 ARDL Cointegrating and Long Run Form

Dependent Variable: DLOG(Y)
Selected Model: ARDL(3, 4, 2, 4)

Cointegrating Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DLOG(Y(-1), 2)	0.729792	0.242899	3.004509	0.0110
DLOG(Y(-2), 2)	0.285290	0.195355	1.460367	0.1699
DLOG(K, 2)	0.152188	0.036364	4.185164	0.0013
DLOG(K(-1), 2)	-0.095522	0.041229	-2.316899	0.0390
DLOG(K(-2), 2)	-0.114191	0.040888	-2.792773	0.0163
DLOG(K(-3), 2)	-0.099069	0.034597	-2.863467	0.0143
DLOG(AM)	-0.003715	0.012899	-0.287986	0.7783
DLOG(AM(-1))	-0.043514	0.015669	-2.777062	0.0167
DLOG(AX, 2)	-0.010157	0.038019	-0.267158	0.7939
DLOG(AX(-1), 2)	-0.019182	0.021651	-0.885982	0.3930
DLOG(AX(-2), 2)	-0.021507	0.017953	-1.197974	0.2541
DLOG(AX(-3), 2)	-0.049448	0.016690	-2.962767	0.0119
ECT_{t-1}	-1.107886***	0.258400	-4.287478	0.0011

Cointeq = DLOG(Y) – (0.4999 * DLOG(K) – 0.0002 * LOG (AM) + 0.0275 * DLOG(AX) + 0.0441)

Notes ECT denote Error Correction Term
*** denote significance at 1% level

Table 4 WALD Test/Short run in ARDL Model

	Dependent Variable: DLOG(Y)
Log(K)	0.0174**
Log(AM)	0.0955*
Log(AX)	0.0823*

Note ***, ** and * denote significances at 1%, 5% and 10% levels, respectively.

short-run coefficients by employing the WALD test which is including in the ARDL model. Table 4 represents the short-run relationship between variables.

The results in Table 4 indicate a positive and significant effect of domestic investment, agricultural imports, and agricultural exports on economic growth in the short run. The impact of agricultural imports and agricultural exports on economic growth is characterized by a weak significant in the short run.

The estimated ARDL models have passed a series of diagnostic tests to ascertain the robustness of our empirical results. The diagnostic tests are comprised of serial correlation, heteroskedasticity tests, the normality of residual term, Durbin-Watson test, R-squared, and Adjusted R-squared are all associated with the empirical equation.

Table 5 reported the results of residual diagnostic tests. Heteroskedasticity tests, Serial correlation LM test, the

Table 5 Diagnostics Tests

Residual Diagnostics Tests	Dependent Variable: LOG(Y)
Heteroskedasticity Test: Breusch-Pagan-Godfrey	0.9353
Heteroskedasticity Test: Harvey	0.1076
Heteroskedasticity Test: Glejser	0.6531
Heteroskedasticity Test: ARCH	0.8312
Breusch-Godfrey Serial Correlation LM Test:	0.2951
Test of Normality	0.136979
R-squared	0.952393
Adjusted R-squared	0.888917
F-statistic	15.00392
Prob(F-statistic)	0.000015
Durbin-Watson stat	1.930499

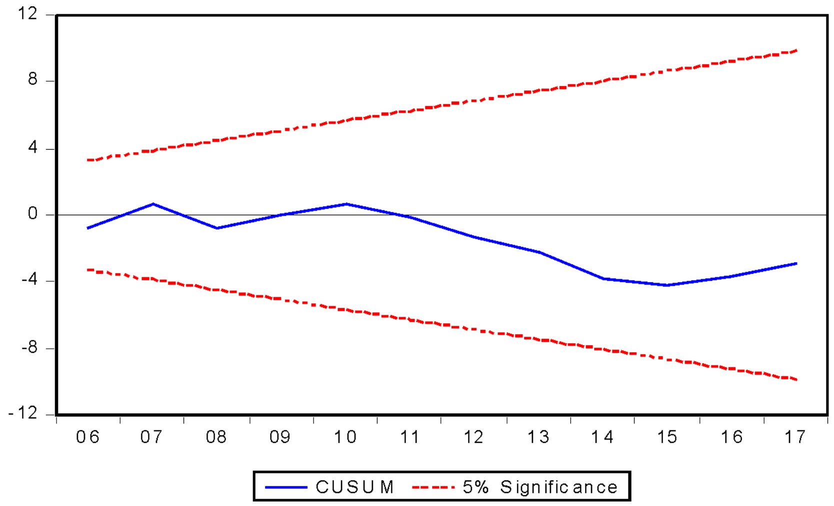

Figure 2 CUSUM Test

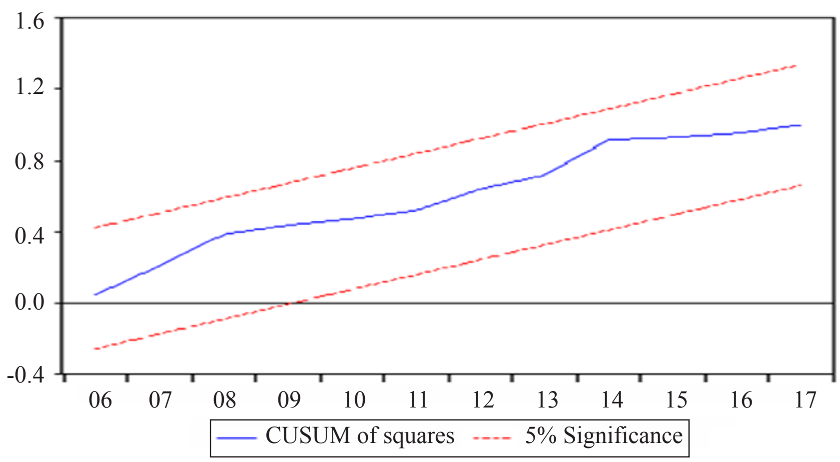

Figure 3 CUSUMsq Test

test of Normality, R^2, Adjusted R^2, Fisher statistic, and Durbin-Watson test indicate that the adopted specification is globally satisfying. The stability test of long-and-short run estimates is tested by using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares (CUSUMsq) of recursive residuals. Figs. 2 and 3 show the results of stability tests such as CUSUM and CUSUMsq.

The results of CUSUM and CUSUMsq tests indicate that graphs of both are between the critical bounds at 5% level of significance. This confirms that the ARDL parameters are stable and efficient.

Conclusion

The agriculture sector plays a key role in the economy in terms of satisfying the domestic and foreign demand which leads to creating more jobs and opportunities. As one of the greatest agricultural trade economies, China has many opportunities in terms of the trade of agricultural products. Since the beginning of the third millennium, the Chinese agricultural exports increase at a strong pace. In this context, this paper aims to answer the question if the agriculture trade promotes Chinese economic growth by employing the ARDL bounds testing for the study period from 1984 to 2017. To the best of our knowledge, this is the first paper that attempts to treat the agriculture trade contribution to economic growth, by considering the agriculture trade as a determinant factor of the Chinese growth model.

The long-run findings revealed that domestic investment and agricultural exports have a positive effect on economic growth. However, agricultural imports have a significant negative impact on growth. In the short run, our highlights revealed a positive and significant effect of domestic investment, agricultural imports, and agricultural exports on economic growth. The positive impact of agriculture exports on growth is due to the importance of agriculture in terms of creating jobs and opportunities for the economy. Besides, sufficient national investment in the agriculture sector tends to enlarge these opportunities and then improves the Chinese economic growth. Furthermore, the negative impact of agriculture imports on growth is justified by the absence of a real contribution of imports to growth, even China is an export economy.

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Received 23 July 2022 Accepted 5 January 2023

Agricultural Economics Research Review 2023, 36 (1), 77-86
DOI: 10.5958/0974-0279.2023.00006.X

Essentially derived variety concept in plant variety rights protection system: underlying economic theories, and issues in implementation

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Abstract Under Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement, World Trade Organization member-countries are mandated to create Intellectual Property Rights (IPR) system for plant varieties. Keeping in view specificities of plant breeding sector, "tailored" IPR system of Plant variety rights/ Plant Breeders' Right system was developed. The concept of Essentially Derived Variety (EDV) was introduced into plant variety protection system through 1991 UPOV convention. In this backdrop, in the current study an attempt has been made to trace theories underlying, and rationale behind EDV concept by reviewing economic models of innovation. The study documented some challenges in implementation of EDV concept and also examined EDV status in India and future prospects.

Keywords Intellectual Property Rights, Plant varieties, Essentially Derived Varieties

JEL codes O3, Q22

Under Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement, World Trade Organization (WTO) member countries were mandated to create Intellectual Property Rights (IPR) system for plant varieties in the form of patents or sui-generis system or combination of both. Many countries opted for system of International Union for the Protection of New Varieties of Plants (UPOV). UPOV convention was revised several times, latest in 1991, when the concept of "Essential Derivation" was accepted into UPOV 1991 convention. According to UPOV 1991 convention, a variety shall be deemed to be Essentially Derived Variety (EDV) when three conditions are cumulatively fulfilled. The conditions are (i) EDV is predominantly derived from the Initial Variety (IV) (ii) EDV is clearly distinguishable from the initial variety, and (iii) except for the difference which results from the act of derivation, the EDV conforms to the initial variety in the expression of the essential characteristics that result from the genotype or combinations of genotypes of the initial variety (UPOV, 2017). EDVs are special in that their developments do not require any authorization from the breeder of the IV from which the variety is developed, (due to "research exemption" clause in Plant Variety (PV) rights protection system) but their marketing requires the authorization from the breeder of the IV. So far, 65 UPOV member states included EDV concept in their Plant variety Right laws (Krieger et al., 2020). Recently, China(a member of UPOV according to 1978 convention) introduced EDV concept in its seed law which became effective from March 1, 2022 (Zhao,2022; Cohen,2022). Starting from 2009, UPOV has released three explanatory notes regarding EDV, the latest one in 2021 and the same is under discussion. However, the explanatory notes is *not binding* on UPOV members, and must not be interpreted in a way that is inconsistent with the relevant UPOV Act (Krieger et al., 2020).

EDV provision is also included in Plant Variety Right laws of three non-UPOV member-countries viz., India, Malaysia and Thailand (Smith, 2021). India has developed its own sui-generis system and enacted Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act in 2001. Under this Act, EDV developers can apply for registering their EDVs. This is in contrast to provision in other countries wherein EDVs have to be established only by claim of the IV developer. In this backdrop, in the following section an attempt has been made to trace the theories underlying and rationale behind EDV concept by reviewing economic models of innovation. In the third section, issues in implementation of EDV provision, ongoing discussion and suggestions are presented and discussed. Status of implementation of EDV provision under Indian PVP legislation is presented in the fourth section. Concluding remarks are made in the last section.

Economic theories and rationale underlying EDV concept

IPR provides ex-ante incentive for innovation. But IPR can also stifle innovation by limiting access to proprietary knowledge/ protected innovations, more so in the case of cumulative and sequential innovations (Scotchmer 2006, Moschini and Yerokhin, 2007). Cumulative innovations are innovations wherein each innovation builds on prior innovations (Scotchmer, 1991; Scotchmer, 2006). Cumulative innovations can also be sequential innovations like (i) a single innovation leading to many second generation innovations (ii) a second generation product requiring the input of many different first generation products often called research tools and (iii) quality ladder model in which firms create successively better products, each improving on the previous one (Scotchmer,2006). In these kinds of innovations, the challenge in designing IPR system is to preserve incentives for initial innovator and also successive innovators without stifling the innovation process. Several research studies focused on this issue (Scotchmer,1991; Green and Scotchmer,1995; O'Donoghue,1997; Reichman,2000; Scotchmer,2006; Moschini and Yeokihin,2007, Bessen and Maskin,2009; Menell and Scotchmer,2019, Parra,2019). Many of these studies focus on particular type of IPR viz., patent and identify policy levers of "fluidity of the market for license" (Menell and Scotchmer, 2019), "patent length" and "patent breadth" i.e forward protection (O'Donoghue, Scotchmer and Thisse, 1998; Scotchmer, 2006, Parra, 2019) and "compensatory liability" regime (Reichman, 2000) for handling the incentive issue.

Cumulative invention/innovation can be of four types based on breadth of initial innovation (i.e., presence or absence of forward protection) and protection status of follow-on innovation. They are (i) protected and non-infringing, giving best incentive for second generation innovator (ii) unprotected and non-infringing, stifling second generation innovation unless there is a mechanism other than IP to protect the innovation, (iii) protected and infringing, leading to blocking protection and encouraging the inventors to share profit from the subsequent invention and (iv) unprotected and infringing, discouraging subsequent innovation in the absence of ex-ante bargaining (Menell and Scotchmer, 2019). Treating forward protection as probabilistic, Parra (2019) examined the effect of different combinations of patent length and forward protection in accelerating innovation in different types of markets. Parra (2019) showed that short patents with strong forward protection are preferable in markets where innovations are relatively cheaper. On the contrary, long patents with weak forward protection are preferable in markets where innovations are costly. Forward protection always discourages entry (Parra, 2019). Longer protection may encourage or discourage entry depending on the level of forward protection (Parra, 2019). Under strong forward protection, longer patents not only delay Research and Development (R&D) investment towards the end of the patent's life but also decrease the number of firms competing in R&D market (Parra, 2019). Metzger and Zech (2020) focusing on plant varieties reported that the broader the exclusive right of the first inventor, the stronger the incentive to make such inventions. On the other hand, the broader the exclusive right granted to the first inventor, the lower the incentive for follow-on inventions. According to Reichman (2000) liability (use now pay later) approach can widen the number of innovators exploiting protected innovation/ information along different trajectories.

There was intense debate regarding necessity of IPR in plant varieties development industry and its consequences (Prasanna, 2018). But it was opined that in plant breeding industry also, IPR protection is necessary to prevent competition through blunt imitation of innovative plants developed through resource intensive research (Metzger and Zech, 2020). The specific issue in the sector is that the subject matter of protection “plant variety” is self-replicating and hence can be easily copied. Hence, plant breeding sector “tailored” IPR system of Plant variety rights/ Plant Breeders’ Right system was developed. Development of new plant varieties is a cumulative and sequential innovation process. All the three types of sequential innovations mentioned in previous paragraph are relevant in plant breeding industry. Under PVR system, “research exemption/ breeders’ exemption provision” is included to ensure accessibility to proprietary genetic material and protected varieties in new varietal development. Thus, under PVR system, effective protection is de facto limited to enforcement against third parties who deal with the protected variety as such or with parts thereof. Under PVR system, there is no protection against third parties who use protected varieties for development of new varieties with minor modification/adaptations and become competitors. Hence, in order to preserve incentive for successive innovators without stifling innovation process, by checking erosion of incentives under PVR regime due to “unconditional breeder exemption” the concept of EDV was introduced in 1991 UPOV convention (Sanderson, 2006, Wiirtenberger, 2013; Bostyn, 2020, Krieger et al., 2020). The purpose of EDV is to limit unfair free riding on the original plant breeder’s time and investment (Lawson, 2014; Lawson, 2020). Further restricting the value of PVRs significantly, possible claims by patent owners for gene and gene combinations introduced into material of protected varieties, causing a one sided dependency of breeders is yet another motive for introducing the EDV concept (Wiirtenberger, 2013). If a New Breeding Technology (NBT) is protected by a patent, the patent holder (of a derived variety using NBT) can prevent the breeder of the IV from commercializing his variety or even to further breed with it. In order to prevent such a situation (with a focus on GMOs) the EDV concept was established (Krieger et al., 2020).

In 1991 UPOV was modified in two important ways, the term of protection was increased from 15 to 20 years and dependency concept based on “genetic distance” was introduced. In other words patent length was increased and forward protection was introduced. But the increased term of protection under UPOV 1991 has not worked as has been hoped because of the development of a suite of new technologies (high-throughput molecular marker capabilities, genomics and off-season nurseries) that enabled breeding procedures to be greatly accelerated (Kingston, 2007). Decrease of lead time advantage in research due to New Breeding Technologies (NBTs), very narrowly interpreted requirement of “distinctness” (based on physically observable phenological, morphological or physiological differences) under PVR system making IPR protection less effective, were also the rationale behind introducing EDV concept (Sanderson, 2006, Manno, 2019; Bostyn, 2020; Metzger and Zech, 2020; Bostyn, 2021). EDV concept introduction in UPOV 1991 Act was to strengthen the breeder’s rights by creating a balance between scope of new breeding techniques and traditional breeding (CIOPORA, 2016; Krieger, 2021). The EDV concept besides preventing the negation of plant breeder’s variety rights, is intended to provide incentives for “prebreeding” or “germplasm enhancement” the time consuming long process of breeding traits from a wild species or landrace into commercial breeding stock (Lesser, 2005). The concept of “genetic distance” or dependency was introduced to enable breeders to benefit from improvements to their varieties made by others (Kingston, 2007).

Determination and regulation of essentially derived varieties

According to UPOV, only varieties that are the result of classical breeding work qualify for the extended protection provided by the EDV concept (Krieger et al., 2020). The dependency of an EDV starts with the beginning of the provisional protection of the IV and ends with the end of protection of the IV. However, there is no consensus regarding how the EDV’s conformity with initial variety needs to be evaluated in terms of traits and test statistics. According to the UPOV 1991 convention, EDVs may be obtained for instance by the selection of a natural or induced mutant or of a somaclonal variant, the selection of a variant individual from plants of the IV, backcrossing or transformation by genetic engineering. But it does not imply that all varieties developed using these methods are EDVs and UPOV 1991 convention does not exclude the possibility of obtaining an EDV by using other breeding methods (UPOV, 2017). According to UPOV (2017), degree of conformity must be judged based on the essential characteristics which result from the genotype of the IV. Essential characteristics are heritable traits that contribute to the principal features, performance or value of the variety and are characteristics that are important from the perspective of the producer, seller, supplier, buyers, recipient or user and may be different in different crop species (UPOV, 2017). Essential characteristics are not restricted to those characteristics that relate only to high performance or value and also may or may not be phenotypic characteristics used for the examination of Distinctness Uniformity and Stability (DUS) test.

International Seed Federation (ISF) and American Seed Trade Association (ASTA, 2020) suggested "genetic conformity" and "generally accepted thresholds" in determining EDVs. It is viewed that appropriate use of DNA markers can provide a largely unbiased estimate of relatedness and similarity between two varieties as DNA markers lack sensitivity to environmental factors (Jamali et al., 2019; Yu and Yong, 2021). Accordingly, based on genetic distance based concept, guidelines were developed for some crops for establishing dependency initially. But, Troyer and Rocherford (2002) showed that agronomic trials were better identifiers of dependent EDVs than molecular markers alone. It was realized that a quantitative approach might not always provide the desired answers (Sanderson, 2006, Bostyn, 2020) as thresholds may vary with plant species (based on total genetic variability), and also due to possibility of manipulation of "methods" of measurement. Some felt that the question of genetic conformity becomes relevant only when it is clear that the phenotypic characteristics is of such similarity to the protected variety that a predominant derivation is likely (Wiirtenberger, 2013). Manno (2019) inferred that the exclusive use of genetic distances to determine essential derivation is not suitable for all plant varieties as there is need for phenotypic variations to be based on genotypic variation. Derivation cannot and should not be examined and identified purely on quantitative grounds. Cultural and practical values are also important in examining and identifying EDVs (Manno, 2019). Effect of evolving NBTs may not be reflected by the agreed upon genetic thresholds, necessitating monitoring and changing thresholds over time (Sanderson, 2006, Manno, 2019). Manno (2019) and Lawson (2020) reported case laws with contradictory rulings about issues concerning EDV assessment based on DNA tests, with some courts favouring phenotypical differences over genotypic differences. Different courts also differed in considering "what were the essential characteristics" (Lawson, 2020). According to UPOV (2017) EDV must retain almost the totality of the genotype of the IV and be different from the variety by a very limited number of characteristics. Researchers (Krieger et al., 2020, Bostyn, 2020) and several organizations representing plant breeders spread across the globe viewed that this narrow approach will not support innovation (Julie, 2019).

According to Krieger et al.(2020), first generation varieties resulting from NBT are mutants solely derived from their IV especially in the case of vegetatively propagated plants and hence these direct NBT varieties should be considered as EDVs. Szonja (2021) suggested that in determining whether a variety is EDV or not, there is a need for considering source of differences in putative EDV (regular crossing and selection or derivation) along with conformity in the essential characteristics of the IV. According to Szonja (2021), a variety with conformity in the essential characteristics of the IV together with differences due to derivation constitutes an EDV. Yang et al. (2021) suggested that with genomic markers, any variety submitted for DUS evaluation that failed to pass the minimum distance threshold can be considered for EDVs.

Under Plant Breeder's Right Act 1994 of Australia, a plant variety is defined as EDV if (i) it is predominantly derived from the other plant variety (ii) it retains the essential characteristics that result from the genotype or combination of genotypes of that other variety and (iii) it does not exhibit any important (as distinct from cosmetic) features that differentiate it from the that other variety (IP-Australia). Thus under this Act, a variety cannot be declared an EDV if it contains an important characteristic which differentiates it from the IV and adds to the performance or value of the variety. This approach contradicts the very rationale, and runs the risk of undermining incentives to undertake crossing and selection to improve a more comprehensive array of quantitatively and qualitatively inherited traits in favour of making small genetic changes to existing varieties (Krieger et al., 2020;

Smith, 2021). In 2018, PBR Act of Australia was amended to allow an application of EDV declaration to be made in instances where the plant variety subject of the EDV application is not registered under PBR act or undergoing application for PBR (IP-Australia). Thus in Australia, there are two separate administrative procedures that can be followed to seek an EDV declaration, depending on whether the newer variety is registered (or under consideration) under PBR act or not.

The above discussion indicated the "limitations of science" in assessing EDVs and highlights the need for assessing essential derivation based on both quantitative and dynamic qualitative aspects (Sanderson, 2006). This will enable the concept of EDV to meet its goal of promoting varietal development at the same time discouraging free riding in plant breeding (Sanderson, 2006). Some researchers proposed "economics" based approach in determining EDVs. According to Wiirtenberger (2013) any activities with a breeding result essentially obtained from a protected IV which endangers the commercialization possibilities of the owner of the initial variety, has to be regarded as dependent. Wiirtenberger (2013) also opines that extending the rights of an owner of an IV regardless of how many distinct additional characteristics the new variety has, simply because it has been obtained by using one initial protected variety would extend the scope of protection of a protected variety far beyond the scope determined by the characteristics, which was certainly not the intention of the legislator.

Payment to lead innovation/ initial variety developer

Parra (2019) focusing on patents in case of sequential innovation in US, reported that the follow-on innovator has to pay a compulsory licence fee equal to the damages caused by the commercialization of the follow-on innovation on infringing innovation. Kingston (2007) focusing on development of plant varieties, suggested a scheme where-in a subsequent developer can pay an amount reflecting the investment and the risk which the originator had taken to bring the "initial variety". Under this system instead of being blocked from entering the originators' market for a term of years (i.e., till the IPR on IV expires), follow-on developer could now obtain a licence to compete by paying to the originator a prescribed payment. Hence. the follower would be in fact sharing the investment and risk of IV developer retrospectively. Bostyn (2020) suggested that a model combining PVR protection for the right holder of the IV and liability for any subsequent user of that variety who uses most of its essential characteristics (i.e user fee) is a fair and feasible answer to the current legal uncertainty in determining EDVs. This system enables the developer of the IV to have share in proceeds of the EDV which in many cases will/can be in competition with the IV and it also provides legal certainty (Bostyn,2020). Bostyn (2021) suggested reward model for EDVs wherein, access to IV will always be guaranteed, but payment of a user fee will be required for commercialization of follow-on plant variety.

Extension of EDV concept

Wiirtenberger (2013) opined that the value of a breeding result which comes into existence without much intervention by its creator does not deserve the same scope of freedom to use the said working result as the breeding result of a person who invested time and money in creating something new. Therefore a party who has created an EDV does not have rights against another party who obtained from that EDV a further EDV. According to UPOV explanatory notes (2017) an EDV itself is not entitled to the EDV extension. However some researchers opine that this may lead to a situation where valuable NBT derived varieties would become easy prey for plagiarism (Kock, 2021). The legislative intent of the EDV provisions does not limit innovative breeding to conventional crossing (Kock, 2021).

There is some confusion regarding who is accountable for determining EDV and who is accountable for solving disputes regarding EDVs. ASTA (2020) views that PVP/PBR authority is accountable for determining if a new variety qualifies for plant variety protection but not for determining whether a variety is EDV or not and solve EDV related disputes.

UPOV 2021 Draft explanatory notes on EDVs

As there are several challenges in determining and regulating EDVs and efforts are on to develop guidelines for handling these challenges. In this backdrop, UPOV released its latest draft explanatory notes on EDVs in the year 2021.

As per this UPOV (2021) explanatory notes predominant derivation concerns the genetic source of the EDV. Predominant derivation means that a variety can only be derived from one IV. “Predominant” derivation means that more of the genome of the IV is retained than would be retained by normal crossing and selection with different parents. However a high degree of genetic conformity alone does not automatically mean that a variety has been predominantly derived. Sister lines from the same cross and two varieties developed through convergent breeding using different parents, though they may have a high degree of genetic conformity may not have relationship of IV and EDV.

Varieties with a single parent (mono-parental varieties) are per se predominantly derived from the IV. Varieties involving the use of two or more parents (multi-parental varieties) may be predominantly derived from one parent (the initial variety) by selectively retaining the genome of the IV. In this case crop-specific genetic conformity thresholds might be defined in order to determine predominant derivation i.e. beyond a level that would be obtained by normal crossing and selection with the IV.

The number of differences between an EDV and IV is not limited to one or a very few differences but may vary taking into account different methods of derivation. The differences may also include essential characteristics. Differences resulting from acts of derivation are disregarded for the purpose of determining the EDV status of a variety.

EDVs can be obtained either directly or indirectly from the IV. If a variety ‘C’ is predominantly derived from variety ‘B’ and variety ‘B’ is a predominantly derived variety from ‘A’ , then variety ‘C’ is EDV from initial variety ‘A’. Only when the initial variety (A) is protected, the EDVs (B,C) fall within the scope of protection of the IV. No rights extend to essentially derived varieties if the IV is not protected. IV cannot be an EDV.

When there is a plant breeder’s right on both the IV (variety A) and an (variety B), the authorization of both the breeder of the IV (variety A) and the breeder of the EDV (variety B) is required for the commercialization of the EDV (variety B). If an EDV(Variety B) is not protected in its own right, third party would require the authorization of the titleholder of variety A only for commercializing B. Once the plant breeder’s right of the IV (Variety A) has ceased, the authorization of the breeder of the IV is no longer required for the commercialization of variety B.

The scope of the breeder’s right applies only to the territory of a member of the Union where the breeder’s right has been granted and is in force. Denomination of EDV shall not be identical to the denomination of the IV.

Members of the Union which amend their legislation in line with the 1991 Act of the UPOV convention may choose to offer the benefits of the 1991 Act to varieties which were protected under an earlier law. For varieties for which protection was granted under the earlier law and for which there is a remaining period of protection which falls under the new law, members can limit the scope of rights on a protected initial variety to essentially derived varieties whose existence was not a matter of common knowledge at the time the new law came into effect. Common knowledge is not restricted to national or geographical borders.

The breeder of the protected IV will also have rights in that variety irrespective of whether the EDV is protected or not. The title holder of the IV may establish predominant derivation (eg. evidence of genetic conformity with the IV by DNA based genetic analysis) or conformity of the essential characteristics. It is a matter for the title holder of the IV to evaluate new varieties commercialized by others and to determine if a new variety may have been essentially derived from their IV. Independent experts to help in this regard are likely to be found in the breeding or plant biotechnology circles or within PBR authorities.

The Working group on EDVs agreed to the following changes to the text of UPOV explanatory notes on EDV (UPOV, 2021).

An essential characteristic is the one that results from the expression of the genotype and includes but is not limited to morphological, physiological, agronomic, industrial and /or biochemical characteristics. An essential characteristic is a characteristic that is fundamental for the variety as a whole. It should contribute to the principal features, performance or value for use of the variety and be relevant for one the following: the producer, seller, supplier, buyer, recipient, user of the propagating material and /or of the harvested material and /or of the directly obtained products and/or the value chain.

An essentially derived variety typically retains the expression of essential characteristics of the variety from which it is derived, except for those differences resulting from acts(s) of derivation, which may also include differences in essential characteristics.

Emerging challenges

Lesser and Mutschler (2004) opined that the UPOV 1991 dependent variety system to be unworkable as the functionality of Plant Variety Protection (PVP) is protecting the entire plant and not specific traits. Further a single relatedness requirement for a species cannot equitably be applied to both discrete and complex traits (Lesser and Mutschler,2004). Lesser and Mutschler (2004) opined that the EDV system with legal uncertainty and associated huge litigation costs, pushes a breeder towards using his or her own or unprotected varieties in his programme rather than the best varieties available and thus often leads to socially inefficient outcomes.

Sophia et al. (2020) in the context of wheat production in Germany reported economic surplus of 19.2 to 22 billion EUR during 1972-2018 due to breeder's exemption in German PVP legislation. Jonge et al.(2021) reported a case study from Philippines where in smallholder farmers have bred and are growing farmers' varieties of maize that resulted from crossing with patent protected crop varieties containing genetically modified traits even in the absence of breeder's exemption in patent law. They reported silent spread of the farmer developed open pollinated herbicide tolerant maize varieties over the last 15 years. On the contrary Manalo and Ignacio (2021) in the context of Vietnam reported that the greater uncertainty about forward rights (EDV or Non-EDV) when a variety is developed from a protected variety, was leading farmer breeders to exclude protected varieties from their breeding work altogether.

The concept of EDV was developed in order to create a counterbalance to the freedom to use the protected varieties for breeding and the freedom to distribute resulting distinguishable varieties in cases where the new variety has been changed only slightly (at least from an economic point of view) (Metzger Axel and Zech Herbert, 2020). However, challenging the EDVs concept's efficiency to reach its above mentioned goal, current definition of EDV allows downstream breeders to get around pre-existing PVRs rather easily. This is either by introducing only the most valuable traits of one variety into another or by implementing relatively unimportant changes which result in a different phenotype, allowing for the assumption that the new variety has not been derived (Metzger Axel and Zech Herbert, 2020).

In some countries there are some Open Source Seed (OSS) Initiatives in which initial plant materials would be freely available to breeders under the condition that the derived varieties from the genetic material, by them would be made available under the same "open source" condition. This is an attack on breeders' exemption (Louwaars, 2019). Plant breeders working under PVR model may not access genetic material from OSS initiatives, as they cannot protect the varieties developed by them (Louwaars, 2019). OSS initiatives by making not only "genetic material" but also "seeds" as open source material enhances competition in seed market (Louwaars, 2019). Under OSS initiatives EDV concept becomes irrelevant limiting its role in checking erosion of incentives in plant varietal development.

Existing PVR systems do not take into account that nowadays it is possible to use a certain variety without access to plant material by solely relying on "Digital Sequence Information" (DSI) (Metzger and Zech, 2020). There is an intense debate regarding (i) proper definition of DSI (Halewood et al., 2018; Aubry, 2019) (ii) appropriate IPR for DSI and (iii) benefit sharing in the context of plant varieties derived using DSI. Defining EDV in the context of DSI is yet another challenge as traceability will be an issue.

Status of EDVs in India

As stated earlier, in India an EDV developer can directly apply to PPV&FR Authority seeking EDV registration. PPV&FR authority guidelines regarding registration of EDVs were published under PPV&FR rules, 2003 as given below.

Candidate varieties of EDVs would need to be tested for one year at two locations for the group of traits not affected by the trait of derivation under protected and natural conditions along with their respective IVs. For EDV of which IV is in public domain, the variety being considered for registration shall be IV for another

Table 1 Crop wise number of EDV applications and EDVs registered

Crop	Number of EDV applications	Number of EDVs registered
Rice	5	
Sugarcane	1	
Sunflower	1	
Tetraploid cotton	141	14
Tomato	3	
Wheat	1	
Total	152	14

Source E- mail communication from PPVFRA

development and permission to cultivate transgenic cotton in India. So far 14 EDVs (constituting 9 percent of EDV applications) have been registered, all from private sector and all were tetraploid cotton varieties. Out of 14 EDVs registered in tetraploid cotton, 8 were transgenic hybrids, 5 were transgenic typical varieties and one was typical variety developed through back crossing. On March 30, 2022, the Ministry of Environment, Forest and Climate Change, Government of India issued notification exempting genome edited products of SDN1 and SDN2 from the provisions of bio-safety regulations in India. This may increase probability of development of EDVs in future.

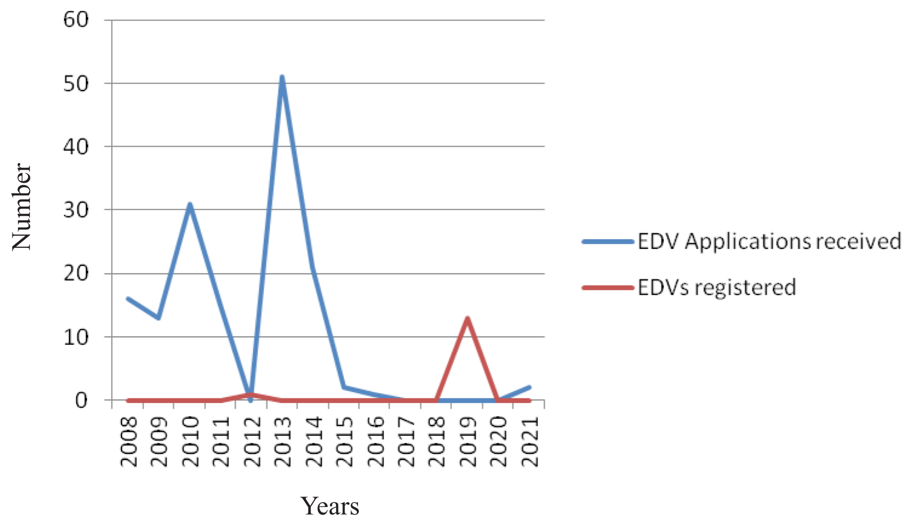

Figure 1 EDV applications and registration progress in India
Source E-mail communication from PPVFRA

variety derived from that variety. Application and prior registration of an IV is pre-requisite for any variety to be considered of its EDV or otherwise it can be considered as a new/extant variety normally.

In India, under PPV&FR Act until 30 November 2021, 17274 applications were received seeking protection. Of these, 152 applications were for registration under EDV category and 14 EDVs were registered (Figure 1). Further, of 152 EDV applications 141 applications were with respect to tetraploid cotton varieties (Table 1). The rest 11 applications were with respect to rice (5), tomato (3), sugarcane (1), sunflower (1) and wheat (1). The higher number of EDV applications in the case of cotton could be due to transgenic cotton varieties

Conclusions

EDV concept was introduced in PVR regime for preserving incentives for IV developer and also follow-on varietal developers in changing techno-social conditions and is in line with cumulative and sequential innovation theory. However, complexity of the subject matter (plant genetic resources), and lack of consensus on "attributes" to be considered in arriving at "Essential Derivation" is posing challenges in establishing and regulating EDVs. This is creating a legal uncertainty which in turn will affect incentives and can lead to sub-optimal use of plant genetic resources. Emerging DSI regime, wherein there is delinking of access to physical (plant genetic) material and plant varietal development, is yet another emerging challenge in implementing EDV concept.

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Received 23 July 2022 Accepted 14 February 2023

Agricultural Economics Research Review 2023, 36 (1), 87-101
DOI: 10.5958/0974-0279.2023.00007.1

Agricultural development in recent decades and welfare challenges

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Abstract While economic development is dependent on performance of agriculture sector, rural areas have been facing skewed land distribution, falling agricultural investments and rising cost of cultivation. Land fragmentation forces rural households to straddle between employment in agriculture and non-agricultural activities. The paper examines linkages of agricultural growth with overall economy, performance of agricultural sector and declining support to it. Sectoral labour productivity, wage differentials and income are examined to contextualize wellbeing of households across states and size continuum. Policy focus needs to be on measures to aid inclusivity and wellbeing of rural workers.

Keywords: Agricultural output, non-farm employment, labour productivity, agricultural investment, Agricultural income, cultivators, sectoral linkages

JEL codes Q100, Q110, Q180, Q150

Introduction

Since the early 1980s, the agricultural sector has undergone several changes, including fragmentation of landholdings, regional variations in its performance, and agrarian crisis due to rising cost of cultivation, indebtedness and farmers' suicides. Agricultural growth, owing to its backward and forward linkages with other sectors is an important determinant of economic development. In India, agricultural sector contributes about 16% to the gross domestic product (GDP), and engages 45% of the workforce.

The agricultural sector faces several challenges, especially of the excessive employment pressure and fragmentation of landholdings. The average size of landholding has declined from 2.28ha in 1970-71 to 1.08ha in 2015-16. The small and marginal landholdings (less than or equal to 2ha) comprise 86% of the total land holdings. While, the economy is marked by acceleration in demand for certain services, notably financial, business and personal services, the higher growth in services sector is accompanied by slowdown in labour-intensive manufacturing sector. The employment in services sector too has been growing at a slower rate than its output primarily because of its requirement of highly skilled and educated workers.

Agricultural growth linkages

Economy-wide impact of growth in agricultural sector is highlighted by the extant literature. Agricultural growth has for long been recognized as an instrument for poverty reduction. With acceleration in agricultural output, rise in agricultural incomes enable farmers to spend more on non-farm goods and services creating a multiplier effect in the economy, rise in wages and reduction in income inequalities (Mellor 2017). Sustained GDP growth attained by developing countries was largely preceded by agricultural growth in the early phases of development. Linkages become clear by gauging the fact that agricultural growth with the adoption of green revolution technology was a major driver of poverty reduction in rural areas (Ravallion and Datt 1996, Ahluwalia 1978). It was estimated that every one percent increase in agricultural productivity was accompanied by reduction in percentage of population living on less than US $/day by 0.6 to 1.2% (Thirtle et al. 2001). The share of rural component in aggregate decline in poverty was estimated to be more than half of the observed decline (de Janvry and Sadoulet 2010). Overall, the pace of poverty reduction was defined by localized factors such as agricultural wages, land ownership, indebtedness and income inequalities.

Agricultural growth is crucial in stimulating opportunities in the non-farm sector and economic transition towards a broader based rural transformation. Agricultural growth can stimulate food processing industries and subsequently the rising demand by rural consumers also support small and medium enterprises. Extent of linkage between agriculture and industry is evident as 10% increase in agricultural output is shown to increase industrial output of 5% (Rangarajan 1982). However, the economy has undergone significant transformation since then (Cortuk and Singh 2015). Experience of the last two decades in terms of agricultural-industrial production linkages (as seen through input-output ratios) is also noteworthy. Since 2003-04, input requirement for industrial sector from agriculture has increased. Agriculture too is dependent on industry for inputs and machinery (Mehta 2015). Impact of such trends could be reduction in poverty and consumption inequality and reiterates that agricultural sector retains a defining role in determining economic growth through its linkages with other sectors.

Increase in food prices hurt poor the most. This necessitates stabilization of food prices through interventions in food markets. Shifts in economic strategy in several countries pursuant to reduction in public investment in agriculture in the 1980s, pushed agriculture as a low priority sector and led to falling productivity levels. Increase in food prices impinge on food security concerns (Grewal et al. 2012). Food inflation owing to slack in output compared to demand may also affect wages. In the absence of agricultural exports and price collapse of even commercial crops that are not under support prices, growers may be subjected to distress and poverty. Despite the need for serious assessment of socio-economic conditions that facilitate poverty amelioration, role of agricultural research and development and technical progress cannot be emphasized enough. India faces the challenge of low yields, inefficient usage of water and energy and environmental concerns. Innovative technologies are required to meet these challenges posed by climate change. In mechanized agriculture, participation of poor may be minimal unlike subsistence agriculture. Intensity of unskilled labour use in agriculture determines its capacity for poverty reduction (Loayza and Raddatz 2010). Hence, labour-absorbing technical progress, that is also cost-reducing, is crucial for a country like India.

Changes in policy regime can also affect farming sector adversely (Radhakrishna 2010). Agricultural liberalization during the early 1990s exposed Indian agriculture to volatility in international commodity markets. Removal of quantitative restriction and reduction in tariffs adversely affected agricultural sector. Government's role in laying emphasis on non-price imperatives such as rural infrastructure, credit, technology and investments that benefit agriculture is thus important in balancing domestic food prices (Kashyap and Mathur 1999). Greater investment on agricultural research and development, innovation and supportive institutions facilitating growth in rural non-farm employment should be the focus of the policy.

Growth performance of economic sectors

Agricultural sector in the last four decades has shown near stagnant growth. Primary sector contributed to more than half of total output of the economy during the 1950. Thereafter, its share has been declining steadily to around 16% in 2020-21 (Tables 1 and 2).

Table 1 Share of primary sector in workforce and income and relative sectoral product per worker

Years	Share of workforce	Share of GDP (at nominal value)	RSPW
1970-71	72.0*	46.9	0.65
1980-81	68.8*	40.0	0.58
1993-94	64.3+	32.1	0.50
1999-00	61.7+	26.9	0.44
2004-05	59.0+	22.6	0.38
2011-12	47.5+	18.6	0.39
2019-20	45.6++	16.3	0.36

Source EPWRTS for National Accounts data; * Population Census; +Different rounds of NSSO Surveys on Employment and Unemployment; ++ PLFS

Table 2 Changes in sectoral contribution of GDP at factor cost (2011-12 base) (percent)

	2004-05	2011-12	2016-17	2020-21
Agriculture & Allied activities	22.64	18.53	15.24	16.38
Mining & Quarrying	4.56	3.22	3.08	2.37
Manufacturing	15.58	17.39	18.14	16.92
Utilities	2.28	2.3	2.08	2.46
Construction	8.08	9.59	8.09	7.6
Hotels, transport, communication etc	16.74	17.43	18.95	17.73
Finance, Insurance, Real Est & Business Services	19.36	10.9	22.01	23.07
Public Admn, Defence & Quasi-Govt. Bodies	10.75	12.96	12.32	13.47
GDP at Factor Cost	100	100	100	100

Source Computed from National Accounts, CSO

In the early 1970's, agriculture was the principal source of employment engaging 72% of workforce. Its share in employment has declined slowly. Currently, it engages 45.6% of the workforce. Behavior of output and employment in primary sector indicates significant structural changes in the economy. While agricultural sector's share in GDP has been declining, that of manufacturing, utilities and construction has risen to around 27%. However, it is the tertiary sector including financial and business services, hotels, transport/communication and personal and other services that occupy dominant position in the economic output (54%), marginally higher than 47% in 2004-05 (Table 2). After 2000s, whereas growth in agriculture continues to be nearly stagnant (4 to 3.5 %), that in mining, utilities and manufacturing has decelerated. Even within the tertiary sector, with the exception of financial, real estate and professional services, output growth has decelerated (Table 3).

Despite near absence of growth, the agricultural sector continues to be a major source of labour absorption. Thus, any downswing in the sector is bound to have severe consequences for a large segment of the population. A crucial variable in this respect is relative sectoral product per worker (RSPW) or the ratio between income share in GDP and that of workforce. RSPW for agriculture and allied sectors in 1970-71 was 0.65. Since then there has been a rapid decline, 0.50 in 1993-94 and 0.38 in 2004-05. There was however a marginal improvement in 2011-12, but declined afterwards to 0.36 in 2019-20 (Table 1). Falling RSPW implies fall in labour productivity in primary activities and increasing rural-urban inequalities.

Table 3 Compound annual growth rate, GVA & components (2011-12 base)

(percent/annum)

	04/05 to 11/12	11/12 to 20/21
Agriculture, Forestry and Fishing	3.9	3.5
Mining & Quarrying	1.7	1.4
Manufacturing	8.6	4.6
Utilities	7.0	5.7
Construction	9.5	2.2
Hotels, Transport, Communication etc services	7.5	5.1
Financial, Real Estate and Professional services	-1.6	14.0
Public Administration, Defence and Other services	9.8	5.3
GVA at Basic Price	6.9	4.9

Source Same as Table 2

Performance of agricultural output

Prior to independence, agricultural output remained almost stagnant for several decades. Between 1911 to 1941, per capita agricultural output declined by 0.7% per annum and foodgrain output by 1.14% (Blyn 1966). Green Revolution technology in mid-1960's modernized agriculture in northwest India through spread of surface irrigation, supportive infrastructure and introduction of technological options in the crop sector (notably high yielding varieties of wheat), resulting in food grains self-sufficiency. During this period although annual agricultural output increased by around 1.7 percent, inter-regional inequalities exacerbated. During the 1980s, the HYV technology was dispersed to newer areas mainly in central and eastern parts of India and included crops likes rice, pulses and later oilseeds. Spread of technology over a wider area improved agricultural incomes as well as total factor productivity narrowing the regional variations in agricultural development.

Table 4 provides an overview of annual growth in output from agricultural and allied sectors for the post green revolution period spanning 1980-81 to 2019-20. To aid comparison output series from National Statistical office (MOSPI) was spliced (2011-12 base) to form a continuous series. With spread of green revolution technology during the 80s to eastern states, cereal output accelerated by nearly 3 percent and food grains by 2.7 percent annually. Concomitantly, the relative prices of cereals continued with a downward trend all through the 80's decade (Figure 1) and India's reliance on imports for food relaxed. During this decade output of oilseeds, together with sugarcane, cotton and spices accelerated substantially. Livestock sector subsuming milk and products, eggs and fisheries also witnessed high growth. Growth acceleration in high value agricultural commodities was on account of within-primary sector diversification, and reduction in area under coarse cereals. Commensurate to output growth this decade was also marked by reduction in incidence of poverty.

Output from agriculture and allied sectors recorded a decline (from 3 to 2.5 percent) during the reforms decade. Annual growth in output declined for food grains, oilseeds, sugarcane, cotton and other fibers. Within the allied activities, livestock and fisheries

Table 4 Average annual growth rate of output from agriculture & allied sectors (percent) (2011-12 prices)

	1980-81-1989-90	1990-91-1999-00	2000-01-2009-10	2010-11 2019-20
Cereals	2.87	2.01	0.85	1.93
Foodgrains	2.71	1.65	1.02	2.06
Oilseeds	5.59	0.99	2.88	0.42
Sugars	3.39	2.29	-0.45	1.01
Cotton & other fibres	4.68	1.77	7.96	1.29
Beverages & narcotics	3.34	3.83	2.65	-0.76
Condiments & spices	4.14	4.49	4.16	6.59
Fruits & vegetables	2.28	4.72	2.99	2.92
Other crops	0.96	1.97	1.66	-0.46
Output from agriculture	2.79	2.29	2.01	2.01
Milk & products	4.98	3.85	3.40	4.93
Eggs	6.91	3.70	5.03	5.42
Livestock	4.53	3.41	3.80	5.03
Forestry	0.08	0.95	1.59	3.00
Fisheries	5.83	4.57	3.23	7.46
High value agriculture	3.88	3.94	3.47	4.84
Output from agriculture & allied	3.01	2.56	2.48	3.20

Source Derived from Government of India, MOSPI (Various years), "State-wise and item-wise value of output from agriculture, forestry and fishing".

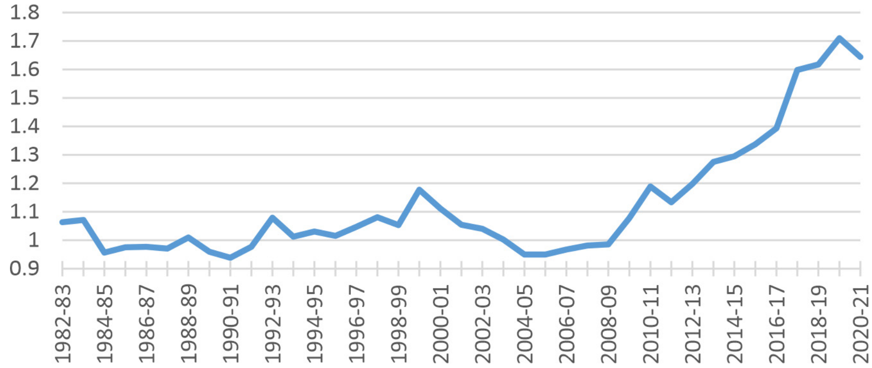

Figure 1 Price trend for cereals, 1982-83 to 2020-21
Note Relative price refers to the ratio of adjusted WPI for cereals and all commodities.
Source Office of the Chief Economic Advisor, Government of India.

sector showed growth deceleration. However, high value crops such as species, condiments and fruits and vegetables as well as 'other crops' recorded growth acceleration. Unlike earlier period 90s decade was marked by a rising trend in relative price of cereals (Figure 1). A peak in cereal prices was attained during 1999-00, that would have hurt the poor impacting on their material wellbeing.

During 2000s decade agriculture output decelerated by 2 percent and did not show much change thereafter. However, output from high value agriculture accelerated from 3.5 to nearly 5 percent in 2010s decade. Fruits and vegetables output slowed down at 3 percent in 2000s decade (from 4.7%) and remained the same thereafter. Livestock sector witnessed an output growth after 1999-00, acceleration being more pronounced in 2010s decade (3.8 and 5 percent). Fisheries recorded unprecedented growth acceleration after 2009-10 (7.5 percent). However, food grain production in 2000s decade decelerated at 1 percent although growth improved thereafter (at 2 % between 2010-11 to 2019-20). Agriculture and allied activities output accelerated from 2.5 to 3.2 percent in the two decades of this millennium.

Despite overall growth acceleration a few crops including beverages, narcotics and 'others' (mostly non-traditional, nonfood crops) witnessed decline in output. As can be observed in Figure 1 the relative price of cereals declined in first half of 2000s decade, but then showed a continuous upward movement. In 2018-19, prices had peaked at an unprecedented high that is fueling the food inflation. Whether this is having a detrimental effect on the lives of net buyers of food grains remains a moot question.

The tardy growth of agriculture in the 2000s decade improved between 2010/11 and 2019/20 (Figure 2),

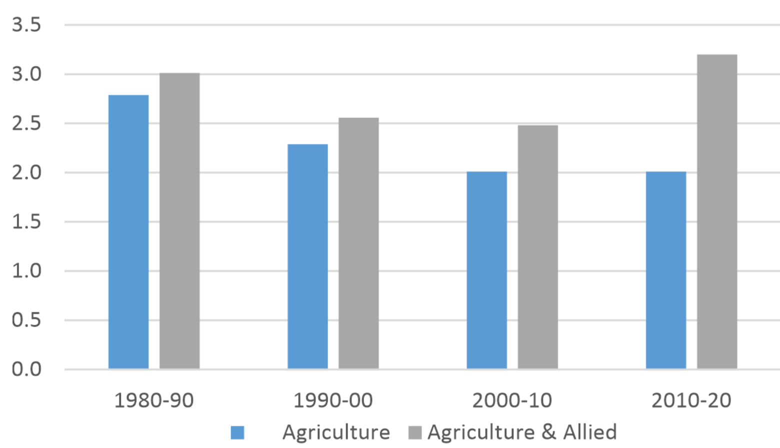

Figure 2 Decadal growth rate of value added of output (%), 2011-12 prices

largely due to better and widespread performance of agriculture in the initial period of Covid pandemic, coinciding with end year of the decade. Stagnancy in output growth coupled with escalating relative prices of food (cereals) is a trend that needs to be reversed for betterment of economic condition of weaker sections. Figure 3 depicts performance of agriculture in the last decade (2010-11 to 2019-20). Food grains with entire crop sector recorded near stagnancy in growth of value of output. Clearly output from allied sectors is showing an upward trend in latter half of the decade starting from 2015-16. Output has an effect on relative prices and is a constraint on effective demand that may impact overall growth and incomes. Growth in livestock sector is favorable for poverty reduction as well as enhancing equity. Livestock related activities employ a significant section of primary sector workers mostly small holders, landless laborers and women. Growth of livestock sector largely benefits poor households, as it accounts for nearly half of the income of the asset poor households (Sharma and Kumar 2011). Moreover, by employing nearly 60 percent of women workers it promotes gender and social equity. Unprecedented growth in fisheries sector after 2010-11 is a welcome trend as it enables poverty amelioration in a subsector that employs largely uneducated and unskilled workers, besides contributing positively to exports of agricultural products. Productivity in the agricultural sector can be spurred through appropriate measures notably, capital investments aiding agriculture growth and rural development. We look at the trends in the next section.

Trends in agricultural investments

Investments on irrigation, research and development play an important role in growth trajectory of primary activities by strengthening their linkages with other sectors. Robust public expenditure on capital formation invigorates private investment in its wake and creates conditions for enhancing output per unit area. During the period spanning 1980-81 to 2020-21, share of gross capital formation in primary sector in aggregate gross capital formation depicted a fluctuating trend (Figure 4). In 1960s and 70s decades the share varied between 12-20 percent, and up to early 1990s it ranged from 15 to 25 percent. However, after beginning of the 90s decade it started a downward trend falling from 14 (1992-93) to 9 percent (1998-99). The period 1999 to 2001-02 again saw an increase in the ratio (13 percent) but the magnitude reduced progressively thereafter reaching 6.4 percent during 2019-20. Share of gross capital formation in agriculture and allied sectors in aggregate GDP during the period 1980-81 to 2020-21 remained steady ranging between 3 to 4 percent. This clearly shows the low priority being accorded to agriculture sector relative to other economic sectors in the gross capital formation.

The disaggregated picture reveals that a large number of states had less than the average (11%) share of agricultural expenditure in total capital formation during TE 2017 (Figure 5). Developed states of Gujarat, Haryana, Maharashtra, in addition to West Bengal, Uttar Pradesh and Jammu and Kashmir reported a higher magnitude of capital expenditure on agriculture - result of favorable polices adopted by the states. Annual growth rate in public agricultural expenditure (TE 2008 to TE 2017) shows spatial variations, being the highest for Punjab, Andhra Pradesh, Odisha and Madhya Pradesh (between 15 to 22 %). It is a matter of concern that states with larger magnitude of

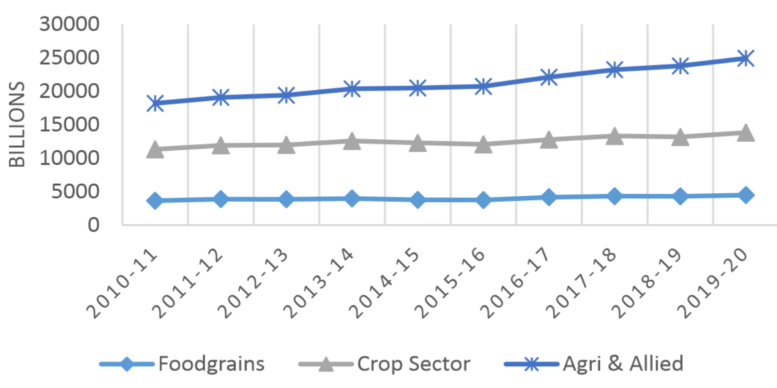

Figure 3 Value of output from foodgrains, crop sector and allied activities (2011-12 prices)
Source CSO data

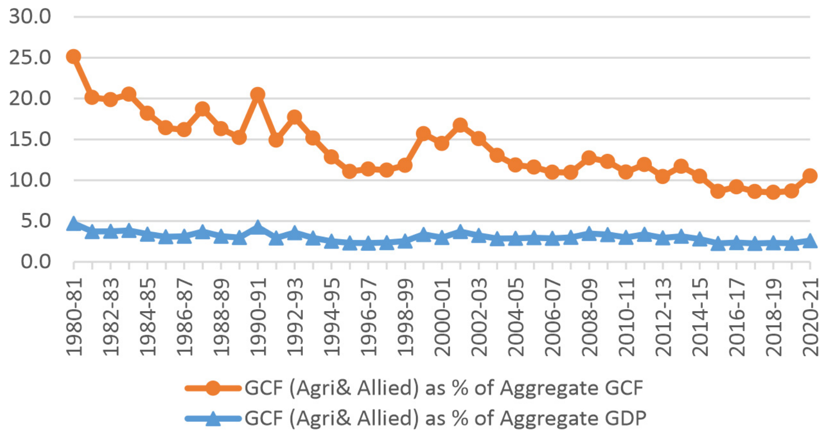

Figure 4 Gross Capital Formation in Agriculture & Allied Sectors as Percent of Aggregate GDP and Aggregate GCF (2011-12 prices)

Source National Accounts Statistics, CSO

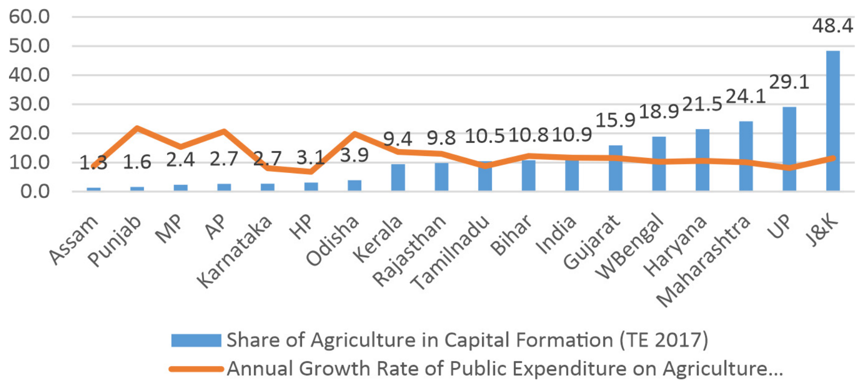

Figure 5 Share of Agriculture in Public Capital Formation and Annual Growth Rate (percent)

Source Finance Accounts, GoI, various issues

agriculture's share in capital expenditure are experiencing a lower rate of annual growth.

Private and public investments in agriculture shared a complementary relationship and till the 80s decade ratio of public and private capital formation in agriculture and allied activities remained nearly same. Subsequently magnitude of public agricultural investments declined. Strength of the relationship between public and private investments weakened and private investments increased up to 2010-11, albeit following a fluctuating path. The rise can be attributed to increased mechanization of farm operations, favorable prices for agricultural products and accessibility to agricultural credit enabling private investments. In recent past (2011-12 to 2020-21) while ratio of public sector GCF in agricultural activities to gross value added hovered at 2.4 to 3 percent (Figure 4), private sector GCF declined from nearly 16 to 13 percent. This resulted in total GCF (public and private) in the primary sector to slide to around 15.5 percent (2016-17). Such a trend coupled with slowdown in agricultural output growth does not augur well for the population dependent on the sector for their livelihoods. It indicates that a renewed focus of policy is required on reviving investments on capital formation and R&D that would bridge yield gaps and enhance output improving the terms of trade in favour of agriculture in the long run.

Wages and trends in labour productivity

Inter-sectoral variations in per capita productivity and wages are examined next. Employment in primary sector (rural and urban) declined from 47.5 percent in 2011-12 to 44.1 percent in 2017-18 (PLFS, UPSS), share in value added however, remained around 15 percent. Secondary sector showed a more balanced

Table 5 Sectoral distribution of rural workers (UPSS) (percent)

	Agriculture		Non-Agriculture	
	Males	Females	Males	Females
NSS 55th round (1999-00)	71.4	85.4	28.6	14.6
NSS 61st round (2004-05)	66.5	83.3	33.5	16.7
NSS 68th round (2011-12)	59.4	74.9	40.6	25.1
PLFS (2017-18)	55.0	73.2	45.0	26.8

trend with a share of 25.2 percent in employment and 31 percent in the GDP (2017-18). Tertiary sector accounted for 53 percent of GDP, as compared to 31 percent of employment. Agriculture sector's predominance in rural areas is evident as it employs 59.4 percent of the workforce, a decline from 64 percent in 2011-12, whereas share in domestic product was 36 percent in 2000s decade. This reiterates the continued disparity in income levels between the sectors, that is bound to affect labour productivity and wages.

Agriculture sector engaged nearly 71 percent of male and 85 percent of female workers in 1999-00. This share has declined noticeably in case of male workers to 55 percent by 2017-18, even though the dependence of female workers on agriculture sector continues to be higher (Table 5). Non-farm sector is emerging as an important source of livelihoods in rural areas engaging 45 and 26 percent of males and females respectively in 2016-17. Shift towards activities such as construction, retail trade and services is necessitated by the need to augment household incomes. There are changes in nature of employment reflected in increase in self-employment (54.5 to 58% between 2011-12 to 2017-18 for rural males), and decline in casual labour in non-farm sector (35.5 to 28 % for males and 35 to 32 % for females). The daily wage earning of rural casual (male) workers accelerated to 9.2 percent (2010-11 to 2019-20) as a result. Proportion of workers engaged in regular employment increased from 10 to 14 percent in the case of males and has doubled for females from 5.6 to 10.5 percent. Regular wage work and self-employment is rising for workers for whom agriculture is increasingly becoming a part time occupation. Wages of rural non-farm workers (skilled, males) grew at 3.9 percent annually in the period following reforms (1993-94 to 2011-12). However, agricultural wages grew faster than non-agricultural wages in the post reform period (Papola 2014). Between 1999 to 2010 agricultural wages grew at 5 percent annually and subsequently (2011 to 2020) the rate accelerated to 9.7 percent surpassing growth rate of non-agricultural wages (9.2 percent). Thus gap between agricultural and non-farm wages has lowered down considerably, even though in absolute terms non-farm wages are set higher than agricultural wages. Mechanization of farm operations and urban wards migration could be fueling such trends. Increased importance of less labour absorbing sectors such as horticulture and expansion of jobs in the non-farm sector could be the other explanatory factors. A look at labour productivity trends across sectors is nevertheless quite revealing.

Labour productivity differentials

Structural transformation encompasses emergence of a dynamic agricultural sector with higher wages that helps in reducing labour productivity gap with non-farm sector thereby eliminating poverty. Typically, labour productivity differentials between the two sectors are minimized when they are well integrated and at higher incomes levels (Timmer 2014). Table 6 represents the trends in sectoral net value added per capita or labour productivity coming from agricultural and non-farm sectors. Defying conventional wisdom over the period 1970-71 to 2020-21 productivity per worker in the two sectors has not converged, but has widened significantly in absolute and relative terms. Difference in the real labour productivity during 1970-71 was nearly Rs.24950 per capita. However, it increased to Rs.109926 by 2020-21. Widening of the gap is evident from the fact that while in 1970-71 labour productivity in primary sector was close to half of non-agriculture, by 2021[1] labour productivity of non-agriculture was nearly three times that of agriculture.

[1]For 2021, rural and urban NSDP was calculated by taking the average share of rural for the period 1970-71 to 2011-12.

Table 6 Labour productivity (Rs/capita), (2011-12 prices)

	Agriculture & allied		Non agriculture	
	Rural	Urban	Rural	Urban
1970-71	23765	19542	48713	106768
1980-81	21831	20498	56990	101648
1993-94	30948	45382	87906	144351
1999-00	37116	76178	110995	207023
2004-05	34394	54216	147314	228062
2011-12	61979	85735	175045	291038
2020-21	57181	70900	167107	277154

Note Sectoral NDP for rural and urban areas is available from National Accounts, CSO. WPRs considered are UPSS rates for the representative or closest NSS quinquinnial rounds and PLFS, separately for rural-urban areas to derive total employment in agricultural and non-agriculture sectors

Source CSO, NSSO, PLFS.

The difference became quite noticeable between 1999-00 to 2011-12. Thereafter non-agriculture sector seemed to show a downward trend in output/capita which could be remnant of impact of pandemic on productivity levels in non-farm activities in rural areas, even though urban labour productivity in non-agriculture shows a far steeper decline.

Since labour productivity is related to wellbeing and poverty levels of workers, it is imperative to arrest widening inter-sectoral inequalities by increasing productivity of land and facilitating transition of workers towards more remunerative non-farm sector. Enhancing the capacities and skills of rural workers especially women and the youth is needed, along with investments in supportive infrastructure. A policy framework that pushes rural industrialization will enable employment diversification (Chand et al, 2017).

Changes in economic wellbeing of rural households

The discussion in previous sections highlights that farm households are facing distress conditions arising from low levels of earnings. Numerous studies (eg. Bhalla 2006, Reddy and Mishra 2009, Chand 2017) highlight this including evidence put forth by the Situation Assessment Surveys (SAS) of NSS. Viability of small holder agriculture is at stake forcing households to undertake wage labour or migrate city-wards to work in construction, repairs, trade and personal services. Slowdown in public investments for agricultural sector and land development has compounded the problem. In order to have a nuanced view we analyze trends in monthly per capita consumption expenditure (MPCE) for rural households. Distribution of rural households while obviously leaning towards agriculture as the principal occupation shows that cultivator households accounting for more than a third of the rural households showed a gradual decline between 1993-94 to 2011-12. However, decline is slower than magnitude of agricultural labour households (from 30 to 21 %) (Table 7a). Households engaged in non-farm sector (both as casual workers or self-employed) recorded a sizeable increase.

The average monthly per capita consumption expenditure (MPCE) during 2011-12 for households engaged in regular services/ professional activities ('other') was highest (nearly Rs.248). It was lowest for agricultural labour households being 63 percent of

Table 7a Distribution of rural households by type of economic activity and average monthly per capita consumption expenditure (30 days reference period)

		% households			Average MPCE (Rs)		
		1993-94	2004-05	2011-12	1993-94	2004-05	2011-12
Self employed	Agriculture	37.8	35.9	34.3	126.9	168.5	199.4
	Non-Ag	12.7	15.8	15.5	124.8	168.3	203.0
Casual labour	Agriculture	30.3	25.8	21.0	93.2	124.7	157.6
	Non-Ag	8.0	10.9	13.5	113.6	149.7	165.8
Others		11.2	11.6	15.7	151.8	230.1	248.2
All		100	100	100	118.9	161.8	195.0

Source Computed from unit level data on state wise MPCEs from NSS Employment-Unemployment Survey. The values are deflated using the CPIAL, CPIRL, 1986-87=100

Table 7b Annual growth rate of MPCE at constant price between 1993-94 and 2011-12 by types of households

Rural areas	Self employed		Casual labour		Others	All
	Agriculture	Non-agriculture	Agriculture	Non-agriculture		
J&K	2.38	2.14	1.82	2.61	3.40	2.42
Himachal Pradesh	3.18	2.93	4.71	2.85	2.70	3.20
Punjab	3.92	3.43	3.00	1.96	3.61	3.18
Haryana	3.44	2.94	4.03	3.09	2.39	3.38
Rajasthan	2.72	3.23	1.14	1.63	2.85	2.58
Uttar Pradesh*	2.63	3.26	3.51	2.93	4.08	3.02
Bihar*	2.06	2.54	3.13	3.00	2.55	2.61
Assam	1.77	2.40	2.47	3.03	2.83	2.33
West Bengal	2.43	2.62	2.58	2.62	2.05	2.44
Odisha	1.93	2.97	2.03	1.66	3.10	2.33
Madhya Pradesh*	1.89	1.90	1.78	1.27	2.68	1.93
Gujarat	2.79	2.46	2.64	1.53	1.99	2.80
Maharashtra	3.09	3.38	3.62	1.99	3.24	3.49
Andhra Pradesh*	3.15	3.63	4.16	3.73	2.90	3.74
Karnataka	3.35	3.63	3.67	3.24	3.09	3.55
Kerala	4.89	3.82	3.93	3.99	3.84	4.27
Tamil Nadu	3.53	3.38	3.48	2.80	2.58	3.49
All India	2.54	2.74	2.96	2.12	2.77	2.79

Source Computed from state wise MPCEs estimated from NSS Employment-Unemployment Survey (unit level data) for 1993-94 and 2011-12. The values are deflated using the CPIAL, CPIRL Base 1986-87=00)

*Refers to states of AP, MP, Bihar and UP before bifurcation

the highest MPCE category. Households self-employed in non-agricultural activities spent 82 percent of 'other' category. Casual labour households whether engaged in agriculture or non-farm activities were most vulnerable, their monthly average expenditure being much below the average of all the rural households (Rs.195 per capita per month). Table 7b depicts state-wise growth rates in MPCE for categories of rural households. Average annual growth rate of per capita consumption expenditure (all households) between 1993/94 to 2011/12 was 2.8 percent but there existed considerable regional variations. Growth rate of MPCE for casual non-agricultural households was the lowest at 2.1 percent. It was even lower than that experienced by households self-employed in agriculture (2.5%). As noted inter-state variations in growth abound. MPCE growth for cultivator households was lowest (less than 2.5 %) in Assam, MP, Odisha, Bihar, West Bengal and Jammu & Kashmir. While Kerala (4.9%), followed by Punjab (3.9), Tamil Nadu (3.5), Haryana (3.4) and Karnataka (3.4) experienced highest growth in MPCE. Amongst agricultural labour households, MPCE growth was lowest in Rajasthan, Madhya Pradesh and Jammu and Kashmir and visibly higher in Himachal Pradesh, Andhra Pradesh, Haryana and Kerala. It is evident that the level of MPCE for agricultural households was quite low in states of Madhya Pradesh, Chhattisgarh, Odisha, Jharkhand, Rajasthan, Uttar Pradesh, Bihar and Assam (Figure 6). These also performed poorly in growth of MPCE for all agricultural households.

Relative wellbeing of rural households does not indicate adequacy of incomes and profitability aspects, given the precarity of returns from cultivation related activities. Trends from Situation Assessment Survey of Farmers are more obtrusive. For agricultural households, average income from all sources (crop output, animal husbandry, wages, non-farm activities) rose from Rs. 6426 to Rs.10218 between 2012/13 and 2018/19 in nominal terms- nearly 57 percent rise, though in real terms increase is by 16 percent only. However, it is essential to look at earnings of

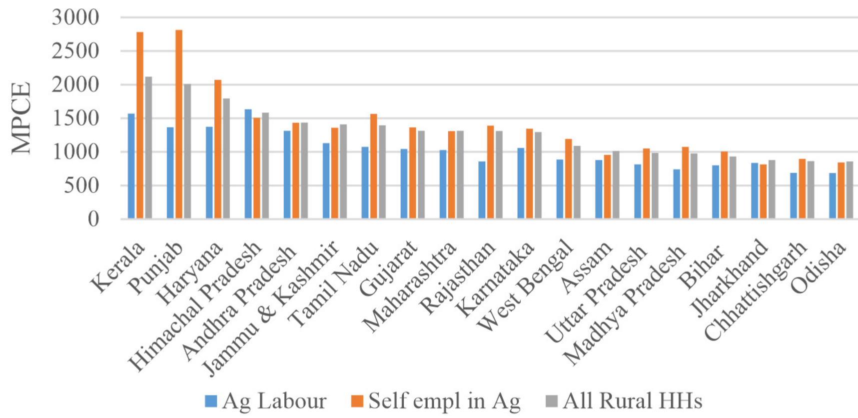

Figure 6 State wise nominal MPCE for Categories of Rural Households, 2011-12

Table 8 Change in real monthly income from agriculture by size class of land, 2012-13 and 2018-19

Size class	2002-03		2012-13		2018-19		Difference	Diff as %
(ha)	(nominal)	(real)	(nominal)	(real)	(nominal)	(real)	in real	of 2012-13
1.01-2.00	1578	2914	4209	4098	5269	3729	-369	-9
2.01-4.00	2685	4958	7359	7166	9432	6675	-490	-7
4.01-10.00	4676	8634	15243	14842	19645	13903	-939	-6
10.00 & more	8321	15364	35685	34747	43499	30785	-3962	-11

Source SAS 2003, 2013 and 2019 (following Swaminathan 2022).

Note Only out of pocket expenses are considered while arriving at the net receipts from agriculture. Nominal values are deflated by using Consumer Price Index for Rural Areas.

households operating marginal parcels of land (<1ha) for whom the returns from crop production may not be adequate. This compels an examination of incomes across land holding categories (Table 8). Over the period spanning 2002/03 to 2012/13 real income from crop production increased for all sizes of landholdings above 1 ha at rates ranging between 41 to 126 percent. However, it is striking to note that after 2012-13 for all sizes of cultivators there was decline in real incomes. In absolute terms the rise in incomes ranged between 22 to 29 percent but in real terms incomes declined by 6 to 11 percent.

To illustrate further it can be seen that a household holding between 1 to 2 hectares earned Rs. 4209 in 2012-13 that increased to Rs.5269 in 2018-19 in nominal terms, an increase by 25 percent. However, after deflating earnings to their real value agricultural incomes actually fell by 9 percent. The overall trend across size classes remains similar, even though magnitude may vary by using alternate price deflators.

Agricultural households are forced to rely on multiple sources of income. Expectedly share of income from crop production rises with size of land possession. The states show wide variations in terms of absolute returns from agriculture, in share of income from agriculture and change in these parameters. Growth in net receipts from cultivation was negative for Jharkhand, Assam followed by Madhya Pradesh, Odisha, Kerala, Telangana, Rajasthan, Uttar Pradesh and Haryana between 2012-13 and 2018-19 (Figure 7). Overall it was estimated that share of crop production in total household income declined from 46 percent (2002-03) to 38.5 percent (2018-19) (Table 9). The rate of annual growth was 5.3 percent between 2002-03 and 2012 and was -1.2% between 2012/13 to 2018/19. The evidence clearly points to a fall in real terms in net agricultural incomes (Narayanmoorthy 2021, Swaminathan 2022). The annual growth in share of income from annual husbandry slowed from 16 to 7 percent and that from wages/salaries doubled from 3 to 6 percent between 2012/13 and 2018/19.

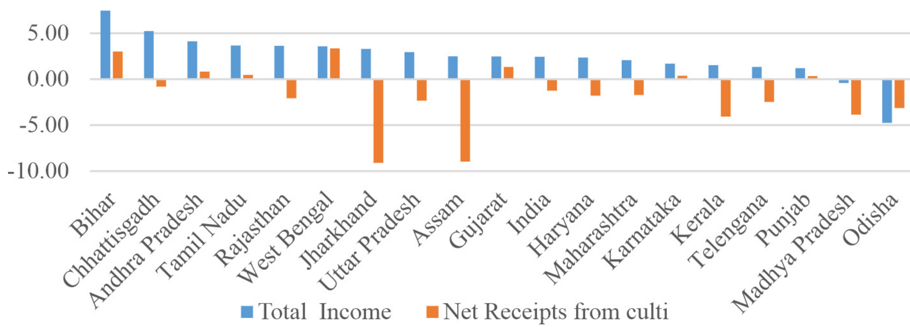

Figure 7 Annual Growth rate of Net receipts from Cultivation and Total Income of Rural Households
Source Computed from SAS 2012-13 and 2018-19. The income is adjusted to real value using CPI for Rural areas(New Series).

Table 9 Share of average monthly income of agricultural households from different sources

	Income (Rs)			Share of activity (%)		
	2002-03	2012-13	2018-19**	2002-03	2012-13	2018-19
Crop production*	1784	3000 (5.3)	2783 (-1.2)	45.8	47.9	38.5
Animal Husbandry*	167	743 (16.1)	1120 (7.1)	4.3	11.9	15.5
Wages/salaries	1507	2017 (3.0)	2875 (6.1)	38.7	32.2	39.8
Non-farm Business	434	499 (1.4)	454 (-1.6)	11.2	8.0	6.3
Total income	3893	6257	7231	100.0	100.0	100.0

Note * net receipts considering paid out expenses
** Includes income from leasing out land in crop production.Figures in brackets are the growth rates.
Source Computed from SAS 2002-03, 2012-13 and 2018-19. The income is adjusted by using CPI AL and CPI for Rural areas (New Series).

Marginal landholders are compelled to participate in ever increasing numbers in the agriculture labour market or take up low paid wage labour or some sort of self-employment in the non-farm sector owing to unrelenting pressure on land. They are crowding in whatever activities are existing-construction, trade, storage, transportation, personnel services or unregistered manufacturing. Distress conditions arise from stagnant returns from crop production, high variability in output and rising cost of cultivation. In recent years' efforts to increase MSP for crops could not offset the rising cultivation costs led by high input prices (Ramakumar 2020).

Way forward

Over dependency on cultivation related activities tends to result in high incidence of poverty. Needless to add high potential exists for improving material wellbeing of agricultural households through creation of non-farm employment opportunities. Evidently non-farm jobs enable diversification of incomes sources besides improving agricultural labour productivity. Such developments in semi-urban areas can promote input-output linkages with the agricultural sector, necessary for overall economic growth.

Agricultural incomes per capita as well as per unit of land can be augmented through specific measures, most important being rise in crop yields and value of output through increased acreage under market-oriented crops in place of subsistence crops. Crucial aspect in this regard is resource use efficiency and replacement of water intensive crops (eg. paddy) with high value crops (fruits, vegetables, oilseeds, pulses etc.) (Birthal et.al 2013). Importance of land reforms, creation of physical infrastructure and human capital development cannot be over emphasized for reducing poverty levels and enhancing overall wellbeing of rural households. Along with this a concerted focus on small and medium enterprise development can be pivotal in creation of rural employment and economic diversification. At the same time self-employment of a sustainable nature can be encouraged through easy access to credit, technology and other productive assets that would unleash the entrepreneurial spirit of rural masses and reduce their dependence on agricultural activities for livelihoods.

Monthly per capita expenditure patterns reflect that in recent times agricultural households experienced improvement in their wellbeing however, they lagged behind those that were self-employed in non-agriculture, regular/salaried and the urban households. Per capita expenditure levels are positively influenced by agricultural productivity and supporting capital infrastructure (irrigation, road networks) besides extension services and urbanization levels. Studies (for instance, Radhakrishna and Raju 2015) concluded that sustainable agricultural development would have to subsume improvement in total factor productivity and within primary sector diversification in addition to income diversification through decentralized industrialization. This would integrate marginal peasantry with development process and improve their economic status. In the Indian conditions a labour intensive approach to development has been emphasized to improve the lot of vulnerable rural households. Creation of decent non-farm job opportunities in fairly large magnitudes will also be crucial for bridging the yawning labour productivity gap between farm and non-farm sectors and improve wage levels. The role of rural organizations is important to give the required push to inclusive growth. These could be in the nature of farmers' organizations, self-help groups, producer companies or cooperatives and federations.

The challenge of agrarian inequalities is also very pressing. Agricultural development is variegated across regions and classes in terms of ownership of productive assets, household incomes and output levels. No doubt the condition of smaller farmers and women farmers is quite precarious and their access to land, outreach, new technologies, prices that they receive etc. is uncertain (Swaminathan 2022). All of this points to the need for public policy that lays emphasis on addressing uneven growth and usher in balanced development.

Emergence of rural non-farm sector today is not so much a result of prevailing conditions in the agriculture sector but is an independent phenomenon, possibly also an outcome of trickling down of urban influences. The influence of urbanism and emerging rural-urban networks impact economic and political landscape of rural areas, emerging trends in crop and non-crop sectors and also change the existing relationships (Mehta 2018). Changes in the countryside as well as in the rural economy require focus of policy and appropriate interventions for a smooth and sustainable transition. It also means that labour market is no longer dependent overwhelmingly on agriculture. Mechanization and technical change are leading to a relative decline in labour demand in agricultural activities. Further, move towards a market-based system indicates the need to focus on creation of social and economic infrastructure and attention to non-price imperatives, chiefly infusion of technology in agriculture. Such steps alone would ensure that households economically dependent on the sector are included in the development process.

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Received 24 April 2023 Accepted 27 June 2023

Agricultural Economics Research Review 2023, 36 (1), 103-110
DOI: 10.5958/0974-0279.2023.00008.3

Temporal changes in crop diversification: A case study in a Punjab village

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Abstract Punjab state is enriched with preeminent but unsymmetrical agricultural base. The significant cotton area shifted towards rice due to insect-pest attack. Besides better irrigation facilities, lower yield risk, assured marketing made rice cultivation more attractive. Diversification towards high-value crops is the need of hour to safeguard our valuable and scarce resources as rice-wheat rotation led to depletion underground water and deteriorated soil health. Therefore, there is a need to set up value addition and processing units in rural areas to enhance the profitability of alternative crops as paddy and wheat.

Keywords Crop diversification, Herfindahl-Hirschman index, economics

JEL codes Q10, Q12, Q15, Q19

The term 'diversification' is been derived from the word 'diverge' which means to move or extend in the direction different from a common point (Jha, Kumar and Mohanty 2000). In agriculture, diversification can be defined as a shift from one crop to another crop, or from one enterprise to another enterprise or to engage in complimentary activities (Vyas 1996). Diversification plays an important role in enhancing agricultural growth and farmers' income, reducing farm poverty, conserving natural resources, reducing climate impacts, and managing threats of insect pests and diseases (Jha et al. 2009, Bezbaruah and Mandal 2013).

Punjab has an important place in India's agricultural economy. The state accounts for 1.53% of the country's geographical area, and 3% of the agricultural land, but contributes 16% and 11% to the total wheat and rice production, respectively. Its contribution to the central pool of wheat is 35-40% and of rice 25-30%. Owing to the nation's food security needs, over the time, Punjab agriculture has moved towards monoculture of rice and wheat. This has led to reduction in agro-biodiversity, and over-exploitation of ground water resources. Procurement of rice and wheat at their minimum support prices is considered to have caused these negative externalities.

This paper examines changes in agriculture in a Punjab village over the past two decades focusing on crop diversification. Analysis at such a micro level provides important insights into the constraints to diversification that need attention of policymakers.

Methodology

Data

The study was conducted in a village of Sri Muktsar Sahib district, which has the highest proportion of rural population in Punjab (72.04%). Then, we selected Gidderbaha tehsil, which has 79.7% rural population. From this tehsil, Lohara village was chosen randomly for selection of farm households. A complete census of farm households was carried out. Farm households were selected from different landholding classes, viz., small (less than equal to two ha of operational land holding), semi-medium (2.5 – 4.0 ha), medium (4 - 10 ha) and large (>10 ha). . There are a total 104 farm households in the village, of which 12 are small, 28 are semi-medium, 48 were medium, and 16 are large.

The data were collected for two time points, i.e., 2000-01 and 2016-17 in a well-designed and pre-tested questionnaire schedule. Notably, both these years were agriculturally normal years.

Method

Herfindahl-Hirschman Index (HHI) was constructed to measure the extent of crop diversification. The index is the sum of squares of the crop shares in the total cropped area. The index is bounded by 1/N to 1. The advantage of this index is that it gives more weight to the crops having larger shares. Herfindahl-Hirschman Index (HHI) is denoted as:

$$HHI = \sum_{i=1}^{n} S_i^2$$

Where, S_i is the proportion of i^{th} crop in the total cropped area and n is the number of crops grown.

The index value is normalized to range between 0 and 1. The value of 1 indicates perfect concentration, and 0 indicates perfect diversification.

$$H^* = \frac{(H - \frac{1}{N})}{1 - 1/N}$$

Where, H* is the normalized Herfindahl Index, N is the number of crops grown, and H is the usual Herfindahl Index.

The Herfindahl Index provides level of concentration, hence to know the level of diversification it is subtracted from 1.

DI = 1-H*

Where, DI is the diversification Index

Mann-Whitney U-test

Mann-Whitney U-test is performed to know the difference in the degree of diversification between 2000-01 and 2016-17.

$$U_1 = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2$$

Where, U_1 and U_2 are the sample statistic for 2000-01 and 2016-17, respectively, and n_1 and n_2 are sample sizes in corresponding years. R_1 and R_2 are sum of ranks assigned to two samples.

The lower value of the sample statistics U_1 and U_2 is taken as statistic U. To test the null hypothesis that both the samples have come from the same population and there is no significant difference in these, we calculate Z-test or p value:

$$Z = \frac{U - m_u}{\sigma_u}$$

Where, $m_u = \frac{n1n2}{2}$ and $\sigma_u = \sqrt{\frac{n1n2(n1+n2+1)}{12}}$

Results and discussion

Changes in agrarian structure

Table 1 compares operational holdings of different farm classes over time. The average landholding size has increased from 5.07 ha in 2000-01 to 5.70 ha in 2016-17, but not for all classes. The increase in its size is confined to medium and large farm classes. The landholding size of large farmers increased significantly from 9.51 ha to 13.74 ha, and of medium farmers from 5.11 ha to 5.85 ha. On the other hand, the landholding size of small and semi-medium farmers experienced a significant decline.

These changes in agrarian structure indicate the presence of an active land market, in terms of sale purchase or renting-in and renting-out, in the village. There is a decline in owned land across all farm classes, but significantly for small farmers—45% as against 7% on average. The changes in the operational landholdings of farmers are due to the increase in leased-in land. For example, in the case of large farmers, leased-in land increased to 5.21 ha, equalling 38% of their operational land in 2016-17 as against 0.61 ha or 6.4% of the operational landholding in 2000-01. The leased-in land has also increased in the case of semi-medium and small farmers, but their leased-out land too has increased. The medium and large farmers rarely leased-out land. These findings indicate an increase in the incidence of reverse tenancy, i.e., smaller farmers lease-out land to larger farmers.

Changes in cropping pattern

There has been a significant change in cropping pattern between 2000-01 and 2016-17 (Table 2). Cotton used

Table 1 Total operational holding of farm households in the selected village

(ha/farm)

Farm class/year		Owned (a)	Leased-in (b)	Leased-out (c)	Total operational holding (a+b-c)
Small	2000-01	2.36	0.23	0.10	2.51
		(93.88)	(9.34)	(4.03)	(100.00)
	2016-17	1.33	0.07	0.25	1.15
		(115.85)	(5.99)	(22.18)	(100.00)
Semi-medium	2000-01	2.79	1.08	0.32	3.56
		(78.50)	(30.49)	(8.99)	(100.00)
	2016-17	2.59	0.60	0.39	2.80
		(92.47)	(21.42)	(13.89)	(100.00)
Medium	2000-01	5.00	0.17	0.06	5.11
		(97.78)	(3.33)	(1.19)	(100.00)
	2016-17	4.76	1.09	0.05	5.85
		(81.38)	(18.62)	(0.90)	(100.00)
Large	2000-01	8.90	0.61	-	9.51
		(93.62)	(6.38)		(100.00)
	2016-17	8.62	5.21	0.10	13.74
		(62.79)	(37.95)	(0.74)	(100.00)
Overall	2000-01	4.70	0.49	0.13	5.07
		(92.81)	(9.66)	(2.48)	(100.00)
	2016-17	4.37	1.47	0.17	5.70
		(76.78)	(25.85)	(3.05)	(100.00)

Note Figures in the parentheses are percent of the total.

to be the main crop in *Kharif* season occupying 39% of the gross cropped area, but it has almost disappeared in 2016-17. The major reasons for its disappearance was the heavy infestation of American bollworm, its resistance to chemicals, and unpredicted/untimely arrival of monsoon rainfall. Paddy emerged as the most important crop in this season consolidating its share to 47% in 2016-17 from about 9% in 2000-01. Over time, Basmati paddy also became popular, raising its area share almost four-fold. Expansion of irrigation, lower production and market risks are main reasons behind upcoming of paddy cultivation.

Wheat remains the most important crop in Rabi season. Its share in the gross cropped area increased marginally from 43% 2000-01 to 47% in 2016-17. Fodder crops are the next most important crops in both the seasons, with a small increase in their area share during this period. Likewise, the area under vegetables *has* also increased but marginally. Cultivation of pulses, oilseeds and coarse cereals has never been favoured in this village. Notably, these changes in cropping pattern hold across all farm classes.

Crop diversification

Diversification indices are presented in Table 3. On the whole, there is an increase in the value of diversification index, from 0.64 in 2000-01 to 0.72 in 2016-17, indicating an increasing tendency of monocropping. The index value for *Kharif* season increased from 0.42 in 2000-01 to 0.60 in 2016-17. The reason for decline in diversification index is the shift from cotton to parmal and basmati paddy. It, however, contracted for *Rabi* season from 0.17 to 0.13 because of disappearance of barley and sunflower from Rabi season.

There is an increase in diversification index across all farm classes, but a significant increase is observed on smaller farms. This holds for both Kharif and Rabi

Table 2 Shift in cropping pattern in the selected village, 2000-01 and 2016-17

(ha/farm)

Crop	Small		Semi-medium		Medium		Large		Overall	
	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17
Parmal paddy	0.08	0.51	0.19	1.64	0.50	3.88	1.72	9.00	0.55	3.67
	(1.61)	(22.01)	(2.62)	(29.31)	(4.91)	(33.39)	(9.04)	(32.78)	(5.45)	(32.29)
Basmati paddy	-	0.48	-	0.98	0.73	1.47	-	4.25	0.34	1.66
		(20.77)		(17.58)	(7.17)	(12.69)		(15.45)	(3.34)	(14.58)
Cotton	2.39	-	3.17	-	3.63	0.11	7.51	0.30	3.96	0.10
	(45.11)		(44.60)		(35.52)	(0.94)	(39.49)	(1.10)	(38.96)	(0.86)
Sugarcane	-	-	-	-	0.13	0.08	-	-	0.06	0.04
					(1.27)	(0.73)			(0.60)	(0.36)
Moong	-	-	-	-	-	-	0.05	-	0.01	-
							(0.28)		(0.08)	
Kharif Fodder	0.16	0.17	0.19	0.17	0.16	0.26	0.19	0.18	0.17	0.21
	(2.98)	(7.22)	(2.67)	(3.11)	(1.54)	(2.23)	(1.00)	(0.66)	(1.67)	(1.89)
Kharif Vegetables	0.02	-	0.01	-	0.02	0.04	0.04	-	0.02	0.02
	(0.31)		(0.11)		(0.24)	(0.38)	(0.19)		(0.20)	(0.21)
Wheat	2.32	0.96	3.30	2.54	4.80	5.33	9.08	13.43	4.77	5.32
	(43.81)	(41.55)	(46.42)	(45.37)	(46.97)	(45.90)	(47.74)	(48.88)	(46.88)	(46.83)
Mustard	0.06	0.02	0.06	0.04	0.09	0.04	0.17	0.11	0.07	0.08
	(1.15)	(1.06)	(0.80)	(1.52)	(0.44)	(0.77)	(0.89)	(0.41)	(0.68)	(0.75)
Barley	-	-	-	-	-	-	0.03	-	0.01	-
							(0.17)		(0.08)	
Sunflower	0.10	-	-	-	0.02	-	-	-	0.02	-
	(1.91)				(0.24)				(0.24)	
Potato	-	-	-	-	-	0.02		-		0.01
						(0.17)				(0.07)
Rabi Fodder	0.16	0.17	0.18	0.17	0.16	0.23	0.19	0.19	0.17	0.20
	(2.98)	(7.39)	(2.56)	(3.11)	(1.54)	(1.95)	(1.02)	(0.71)	(1.67)	(1.78)
Rabi Vegetables	0.01	-	0.02	-	0.02	0.10	0.03	-	0.02	0.04
	(0.15)		(0.23)		(0.16)	(0.84)	(0.17)		(0.16)	(0.39)
GCA	5.29	2.30	7.11	5.59	10.22	11.61	19.02	27.47	10.17	11.36
Cropping intensity (%)	200.00	200.00	200.00	200.00	196.00	198.66	200.01	200.00	198.15	199.37

GCA: Gross cropped area

Note Figures in the parentheses are percentages to gross cropped area. The percentages may vary due to rounding off area under crops.

Table 3 Crop diversification in the selected village, 2000-01 and 2016-17

(Diversification Index)

Farm size category	*Kharif* Season		*Rabi* Season		Overall (*Kharif*+*Rabi*)	
	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17
Small	0.26	0.84	0.28	0.42	0.63	0.84
Semi-medium	0.29	0.71	0.18	0.25	0.61	0.78
Medium	0.69	0.59	0.12	0.15	0.61	0.72
Large	0.43	0.59	0.12	0.06	0.68	0.71
Overall	0.42	0.60	0.17	0.13	0.64	0.72

seasons but with some differences across farm classes. In Kharif season, diversification index decreased for medium farm class. Large farms experienced a decline in diversification index in Rabi season.

Frequency distribution of households by diversification level

Table 4 presents changes in frequency of households falling into different diversification ranges. In *Kharif* season of 2000-01, 81% households had diversification index of less than 0.5, and their proportion decreased to 39% in 2016-17. The proportion of households in the index range of 0.5-0.6 also decreased, from 4.81% to 1.92%. Nevertheless, percent of households falling in the range of 0.6-0.7 increased considerably from 0.96% to 11.54%. The proportion of households falling in the index range of 0.7-0.8 also increased considerably from 6.73% to 18.27%. So is in case of index range of 0.8-0.9.

In *Rabi* season of 2000-01, 87.5% farm households had an index of less than 0.5, which increased to 93.27% in 2016-17. The proportion of households falling in the range of 0.6-0.7 however declined.

The Mann-Whitney U-test is significant for all farm classes (Table A1 in the appendix).

Economics of cropping systems

The results of the economic analysis of major crop rotations is presented in Table 5. As mentioned earlier, cotton was the main crop in *Kharif* season in 2000-01, which was replaced by basmati and parmal paddy in

Table 4 Farm households falling in different ranges of diversification index

(Number of farmers)

Crop season	Small		Semi-medium		Medium		Large		Overall	
	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17	2000-01	2016-17
Kharif										
< 0.5	8 (66.67)	5 (41.67)	22 (78.57)	11 (39.29)	41 (85.42)	21 (43.75)	13 (81.25)	4 (25.00)	84 (80.77)	41 (39.42)
0.5-0.6	3 (25.00)	-	2 (7.14)	-	-	2 (4.17)	-	-	5 (4.81)	2 (1.92)
0.6-0.7	-	1 (8.33)	-	1 (3.57)	-	4 (8.33)	1 (6.25)	6 (37.50)	1 (0.96)	12 (11.54)
0.7-0.8	1 (8.33)	3 (25.00)	1 (3.57)	2 (7.14)	3 (6.25)	9 (18.75)	2 (12.50)	5 (31.25)	7 (6.73)	19 (18.27)
0.8-0.9	-	1 (8.33)	3 (10.71)	14 (50.00)	4 (8.33)	11 (22.92)	-	1 (6.25)	7 (6.73)	27 (25.96)
>0.9	-	2 (16.67)	-	-	-	1 (2.08)	-	-	-	3 (2.88)
Rabi										
< 0.5	6 (50.00)	7 (58.33)	24 (85.71)	28 (100.00)	45 (93.75)	46 (95.83)	16 (100.00)	16 (100.00)	91 (87.50)	97 (93.27)
0.5-0.6	4 (33.33)	5 (41.67)	4 (14.29)	-	-	2 (4.17)	-	-	8 (7.69)	7 (6.73)
0.6-0.7	-	-	-	-	2 (4.17)	-	-	-	2 (1.92)	-
0.7-0.8	1 (8.33)	-	-	-	-	-	-	-	1 (0.96)	-
0.8-0.9	1 (8.33)	-	-	-	1 (2.08)	-	-	-	2 (1.92)	-

Note Figures in the parentheses are percent of total.

Table 5 Economics of major cropping systems, 2000-01 and 2016-17

(Rs/ha)

Crop rotation	Crop	AY	At current prices			At constant prices(Base: 2000-01)		
		(q/ha)	GR	TVC	ROVC	GR	TVC	ROVC
2000-01								
Cotton-Wheat	i. Cotton	22.24	39749	17532	21070	39749	17532	21070
	ii. Wheat	46.95	36504	16363	20141	36504	16363	20141
	Total	-	76253	33895	41211	76253	33895	41211
Paddy-Wheat	i. Paddy	59.30	31871	19195	12676	31871	19195	12676
	ii. Wheat	46.95	36504	16363	20141	36504	16363	20141
	Total	-	68375	35558	32817	68375	35558	32817
Basmati-Wheat	i. Basmati	34.59	41513	19192	22321	41513	19192	22321
	ii. Wheat	46.95	36504	16363	20141	36504	16363	20141
	Total	-	78017	35555	42462	78017	35555	42462
2016-17								
Cotton-Wheat	i. Cotton	22.24	93404	59739	33665	42380	27104	15273
	ii. Wheat	56.83	94874	29546	65328	43047	13405	29640
	Total	-	188278	89285	98993	85427	40510	44915
Paddy-Wheat	i. Paddy	69.19	106021	41407	64614	48103	18787	29316
	ii. Wheat	56.83	94874	29546	65328	43047	13405	29640
	Total	-	200895	70952	129942	91150	32192	58958
Basmati-Wheat	i. Basmati	44.48	130395	39188	91207	59163	17781	41382
	ii. Wheat	56.83	94874	29546	65328	43047	13405	29640
	Total	-	225269	68733	156535	102208	31186	71024

AY: Average yield, GR: Gross returns, TVC: Total variable costs, ROVC: Returns over variable costs

Table 6 Perception of the farmers regarding crop diversification

Particulars	Respondents*	
	Number	Percentage
Climatic conditions	95	91.35
Size of farm	90	86.54
Demand of farm produce	80	76.92
Insect-pest attack	78	75.00
Price risk	75	72.12
Perishability of products	70	67.31
Irrigation facilities	66	63.46
Inputs (Seeds, fertilizers, pesticides, etc.)	63	60.58
Previous performance of crops	47	45.19
Marketing facilities	38	36.54
Duration of crops	38	36.54
Age	34	32.69
Labour availability	28	26.92
Financial risk	19	18.27

Note multiple responses

2016-17. In *Rabi* season, wheat remained the main crop during this period. In 2000-01, the net returns from paddy-wheat rotation were lower than of the cotton-wheat in 2000-01. However, in 2016-17, net returns from paddy-wheat were more than that from cotton-wheat.

Farmers' perception on crop diversification

There are various factors affecting crop diversification. An attempt was made to find out the factors which affect farmers' diversification decisions (Table 6).

Over 91 % of the farmers indicate that climatic conditions are the main decisive factors in crop diversification. Increasing aberration in weather conditions result in production risk. . Another risk in production is the insect pest infestation. An example is the disastrous attack of white fly and American bollworm on cotton, which make farmers' reluctant to grow cotton. There are some crops, of which market prices rarely exceed minimum support price. Perishability of vegetables restrict their cultivation for home consumption alone. On the other hand, paddy and wheat have assured markets. Market risks also act as barrier to one cultivation of crops alternatives of rice and wheat. Some farmers also opine that there is a financial risk associated with the introduction of new crop.

Conclusions

Our findings indicate a decline in crop diversification. Low-water footprint cotton has been replaced by water-guzzling paddy. The main reasons are assured market for paddy and wheat, their high profitability compared to other crops, and low production risks. Initiatives need to wean farmers away from paddy-wheat towards other crops, which are more remunerative and less degrading of natural resources.

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Received 22 June 2022 Accepted 25 December 2022

Table A1 Comparison of diversification indices by Mann-Whitney U-Test

Farm size categories	Diversification index		Mann-Whitney U-Test		
	2000-01	2016-17	U-Statistic	Z value	p value
Kharif Season					
Small	0.26	0.84	34.5	2.17**	0.035
Semi-medium	0.29	0.71	209.5	2.99***	0.004
Medium	0.69	0.59	680.5	3.45***	0.000
Large	0.43	0.59	62.0	2.49**	0.014
Overall	0.42	0.60	2887.5	5.81***	0.000
Rabi Season					
Small	0.28	0.42	67	0.29NS	0.75
Semi-medium	0.18	0.25	359	0.54NS	0.594
Medium	0.12	0.15	1129.5	0.16NS	0.872
Large	0.12	0.06	26	3.84***	0.000
Overall	0.17	0.13	2049.5	7.74	0.284
Overall (*Kharif +Rabi)*					
Small	0.63	0.84	23.0	2.83***	0.005
Semi-medium	0.61	0.78	79	5.13***	0.000
Medium	0.61	0.72	367	5.75***	0.000
Large	0.68	0.71	58	0.02***	0.009
Overall	0.64	0.72	2049.5	7.74***	0.000

***, **Significant at 1 per cent and 5 per cent level of significance respectively

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