ISSN 0971-3441
Online ISSN 0974-0279

January-
June 2024
Volume 37
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. 37 (No.1) 2024

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

Agricultural Economics Research Review

[Journal of Agricultural Economics Research Association (India)]

Volume 37 **Number 1** **January-June 2024**

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Agricultural Economics Research Review 2024, 37 (1), 1-11
DOI: 10.5958/0974-0279.2024.00001.5

Agricultural wages in India: Trends and structural changes

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Abstract In India, the rural labour market is transitioning from the agricultural to non-agricultural sectors. This transition is accompanied by the changes in agricultural wages and labour availability for farm operations due to employment generation schemes like Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) or the disequilibrium in the labour market due to the COVID pandemic. This study has analyzed the trajetorey of agricultural wages and has assessed the impact of MGNREGS and Lockdown to curb COVID infections on these wages at the national and sub-national levels. The study has used the gender-disaggregated monthly labour wages data for three major agricultural operations-harvesting, sowing, and ploughing for the period 1995-2022. The results have revealed a structural change, seasonality, and disparity in agricultural wages across gender and states. Further, the ARIMA-intervention modelling has indicated that the implementation of MGNREGS from 2006 to 2008 contributed significantly to the sharp increase in the real farm wages, and its impact increased over time. The imposition of Lockdown to curb the COVID infections did not cause any significant impact on agricultural wages. Thus, the COVID-led disequilibrium in labour market was only short-lived without any significant impact on agricultural wages in India.

Keywords Agricultural wages, ARIMA, intervention, COVID, MGNREGS

JEL codes E24, R23, J01, J30

Introduction

The rural labour market in India is undergoing a structural transformation from the agricultural sector to non-agricultural sectors and this is characterized by a gradual shift in workforce towards the latter sectors (Venkatesh, 2013; Chand and Srivastava, 2014). This often leads to reduced availability of labour for agriculture and pushes farm wages upwards. Although a higher wage reflects improved standard of living of agricultural labours, it has definite implications on agriculture. In the absence of effective farm mechanization and other measures to address the reduced labour supply, high wages can raise the production cost which in turn would put inflationary pressure on the economy (Chand and Srivastava, 2014). During 1990-91 to 2014-15, average annual inflation in cost A1+Family labour was 10 per cent at the national level and labour cost alone constituted 46 per cent share in the cost inflation (Srivastava et al., 2017). Managing farm labour and adverse effects of wage rise, therefore, becomes an important stragety to reduce the cost of cultivation and improve farm profitability. Notably, the level of farm wages is influenced by multiple factors such as agricultural productivity, pattern of economic growth, adoption of labour-saving technologies, worker productivity, employment support programs like Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), disequilibrium in the labour market caused due to unforeseen incidences such as COVID, etc.

Historically, agricultural wages have shown fluctuations with wide disparity across the states and gender in India. Gulati et al. (2014) noted a relatively higher annual growth of 3.7 per cent in the real farm wages during 1990s as compared to 2.1 per cent growth during 2000s. Further, they observed a v-shape behaviour in real wages during 2000s i.e. wages declined by 1.8 per cent during 2000-01 to 2006-07, followed by a rapid increase at 6.8 per cent annual growth during 2007-08 to 2011-12. Kumar et al. (2020) analysed the movement in wages during 1995-96 to 2016-17 and reported disparity in farm wages across states, gender and agricultural operations. Several scholars have identified the plausible factors that may be influencing agricultural wages (Bhalla and Das, 2005; Berg et al., 2012; Bhattarai et al., 2014; Chand and Srivastava et al., 2014; Gulati et al., 2014; Nagaraj et al., 2016; Kumar et al., 2020; Himanshu and Kundu, 2016; Turangi, 2020). Some of the identified factors influencing the trends in farm wages in the past are: growth in GDP in farm and non-farm sectors, social welfare schemes like MGNREGS, inter-sectoral wages and productivity differentials, irrigation facilities, farm mechanization, skills and education of farm labour, changing labour-employer relationship, etc.

Recently, the country faced unprecended disequilibrium in the labour market caused by the nation- wide lockdown of economic activities to check the COVID infections. The lockdown imposed on March 25, 2020 resulted in the large-scale reverse migration of labour from urban centres to rural areas and thus, increased labour supply in rural areas. The states like Punjab which depend on the migrant contract labours from the eastern states like Bihar for farm operations, faced labour scarcity due to movement restrictions. Only limited evidences exist on the macro-level impact of increased labour availability in the eastern states due to reverse migration and labour scarcrity in states like Punjab due to movement restriction on farm wages. This study contributes to the existing literature by an updated analysis on the trajectory of agricultural wages, seasonal fluctuations and disparity in wages across states, gender and farm operations. Further, we have assessed the impacts of social welfare programs like MGNREGS and disequilibrium caused by the COVID-led lockdown on the agricultural wages in India.

Data and methodology

Farm wages, as a source of income for the agricultural labourers and as a cost component for the cultivators, have significant implications on the rural livelihood and farm economy. We have analyzed trends in agricultural wages both at national level and state level. The gender-disaggregated data on monthly labour wages were collected from the Labour Bureau, Ministry of Labour and Employment, Government of India, New Delhi, for the period 1995-2022 for three major agricultural occupations-harvesting, sowing, and ploughing. The nominal monthly wages have been expressed in real terms using All-India Consumer Price Index Numbers for Agricultural Labourers (CPIAL) (2011-12=100) as deflator. The intra-year seasonality in the wages was checked using Ollech and Webel's combined seasonality test, and de-seasonalised monthly data was utilized for subsequent analyses. The impacts of MGNREGS and COVID shock on agricultural wages has been assessed using 'intervention modelling', a time series analysis used to analyse effects of exogenous forces or interventions in the mean level of series.

Ollech and Webel's combined seasonality test

The seasonal data is a subcategory of time series data that comprises of trends or fluctuations which repeat over the course of pre-determined time periods or seasons. The seasonal patterns may exhibit recurrently rising or falling trends across specific cycles. The presence of seasonality in monthly wages for three major farm occupations-harvesting, sowing, and ploughing-has been tested using Ollech and Webel's combined seasonality test. The combined seasonality test includes a combination of two tests viz, the Kruskal-Wallis test, and the Modified QS test. By default, the Ollech and Webel's combined seasonality test (WO-test) combines the results of the QS-test and the Kruskal-Wallis test (kw-test), both calculated on the residuals of an automatic non-seasonal ARIMA model. If the p-value of the QS-test is below 0.01 or the p-value of the kw-test is below 0.002, the WO-test will classify the corresponding time series as seasonal. If residuals=FALSE, the auto ARIMA settings are ignored. If residuals=TRUE, a non-seasonal ARIMA model is estimated for the time series. The residuals of the fitted model are used as input to the test statistic. If an automatic order selection is used, the Hyndman-Khandakar algorithm is employed with max(p)=max(q) <= 3. The seasonality indices were generated using R Studio software.

Kruskall -Wallis test

The Kruskal-Wallis test is a non-parametric test used to find whether samples originate from the same distribution. The parametric equivalent of the Kruskal-Wallis test is the one-way analysis of variance (ANOVA). When the null hypothesis of the Kruskal-Wallis test is rejected, then at least one sample stochastically dominates at least one other sample. The test does not identify where this stochastic dominance occurs or for how many pairs of groups the stochastic dominance is obtained. The null hypothesis states that all months (or quarters, respectively) have the same mean. Under this hypothesis, the test statistic follows a χ^2 distribution. The test statistic is given by Equation (1)

$$KW = \frac{T-1}{T}\sum_{i=1}^{T}\frac{ni\left[\gamma i-\frac{T+1}{2}\right]}{(T^2-1)/12} \quad \ldots(1)$$

Modified QS test

The modified QS test checks the series {zt} for a significant positive autocorrelation at seasonal lags. Let γ(h) = E (zt+h zt) " E 2 (zt) and ρ(h) = γ(h)/γ(0) denote the lag-h autocovariance and autocorrelation, respectively, of {zt}. Then, the null hypothesis is specified as H0: ρ(k) ≤ 0 for k ∈ {τ, 2τ}. The QS-statistic is obtained as per Equation (2)

$$QS = T(T+2)\left(\frac{\hat{\rho}^2(\tau)}{T-\tau}+\frac{[max\{0,\hat{\rho}(2\tau)\}]^2}{T-2\tau}\right) \quad \ldots(2)$$

Where, $\hat{\rho}(h)$ is the estimated lag-h autocorrelation of {zt}. The exact null distribution of the QS statistic is unknown, but can be approximated reasonably well by a χ^2 - distribution with two degrees of freedom.

Intervention analysis

The Autoregressive Integrated Moving Average (ARIMA) methodology, developed by Box Jenkins, is frequently used for modelling and forecasting in the time-series data. However, the forecasting effectiveness of the ARIMA model may be affected when an intervention, an outside event, impacts the patterns of the time series under consideration. In such situations, the ARIMA-Intervention model can be used. The intervention analysis is an application of modelling procedures for incorporating the effects of exogenous forces or interventions in the time series. It was developed by Box and Tiao (1975). These interventions can be strikes, earthquakes, price changes, floods, pandemics, and other irregular events which causes unusual changes in the time series. The intervention model analyses how the mean level of a series changes after an intervention.

Initially, the best ARIMA model was identified for time series data on wages at the aggregate level, gender-wise, and for major occupations. After that, intervention analysis was done with the best-identified ARIMA model using SAS software.

An intervention model is given by Equation (3)

$$Yt = \frac{\omega(B)}{\delta(B)}B^{b}It + \frac{\theta(B)}{\varphi(B)}\varepsilon t \quad \ldots(3)$$

where,

Y_t= Dependent variable

I_t =Indicator variable: I_t can be before intervention or after intervention. Before intervention, I_t can be indicated by 0 before intervention, and by 1 after intervention.

The intervention type of step function starts from a given time till the last time period. Mathematically, the intervention type of step function is written as:

$I_t = 0 \quad t \neq T$

$I_t = 1 \quad t \geq T$

Where, T is the time of intervention when it first occurres.

Three types of interventions are distinguished by their types: step, pulse/point, and ramp. The step intervention takes place at a specific time in time and its effect continues over time. The impact of a step intervention may not change over time, or it may grow or diminish. A Pulse Intervention takes place only at a specific moment, yet the effects of this kind of intervention may last only for that time period or for a while after. The Ramp Intervention starts at a certain point in time and continues with increasing intensity in the later periods. The impact of ramp intervention constantly grows over time.

In the present study, the intervention points were: February, 2006 and March, 2020, on which the MGNREGS was initiated, and a lockdown to curb COVID was imposed, respectively. The MGNREGS is a step intervention, and lockdown due to the COVID-

19 pandemic was considered a pulse/point intervention. Further, the impact of the lockdown on wages was also analyzed (using intervention analysis) in the states of Punjab and Bihar , which witnessed a large-scale reverse migration of labour during the lockdown. Punjab witnessed labour scarcity, whereas Bihar witnessed an enhanced labour supply. The wages in Punjab were expected to increase (due to labour scarcity) and decrease in Bihar (due to surplus labour). Such expectations were tested using the intervention analysis.

The intervention model consists of three parameters, ω, δ and b.

$\delta(B) = 1 + \delta 1\ B + ... + \delta B^r$: Slope parameter

$\omega(B) = \omega 0 + \omega 1\ B + ... + \omega s B^s$: Impact parameter

$\varphi(B) = 1 - \varphi 1\ B - \varphi 2B^2 - ... + \varphi p B^p$: Autoregressive parameter

$\theta(B) = 1 - \theta 1\ B - \theta 2B^2 - ... + \theta p B^q$: Moving average parameter

where,

εt = White noise or error term

b = Delay parameter

B = Backshift operator, i.e., $B^bY_t = Yt - b$

The intervention model consists of following three parameters.

(1) "δ" – It is known as the slope parameter, and has different meanings in the case of different types of interventions. In the case of step intervention, if is near zero, the effect of intervention remains constant over time, and if is near one, the effect of intervention increases over time.

(2) "ω" – It is known as the impact parameter, which implies a change (either positive or negative) due to intervention.

(3) "b"- It is known as the delay parameter, and it usually takes the values 0, 1, or 2; b=0 implies that the effect of intervention has occurred at the time of intervention itself, and b=1 implies the effect of intervention is felt after a delay of one period, and so on.

Results and discussion

Trends in real agricultural wages at the national level

At the national level, the average agricultural wages have been estimated based on three major farm operations- harvesting, sowing, and ploughing. The nominal wages have been expressed in real terms using CPIAL (2011-12=100) as the deflator. Figure 1 presents the trends in real agricultural wages by gender from 1995 to 2022. It shows that between 1995 and 2006, the real agricultural wages increased only marginally,

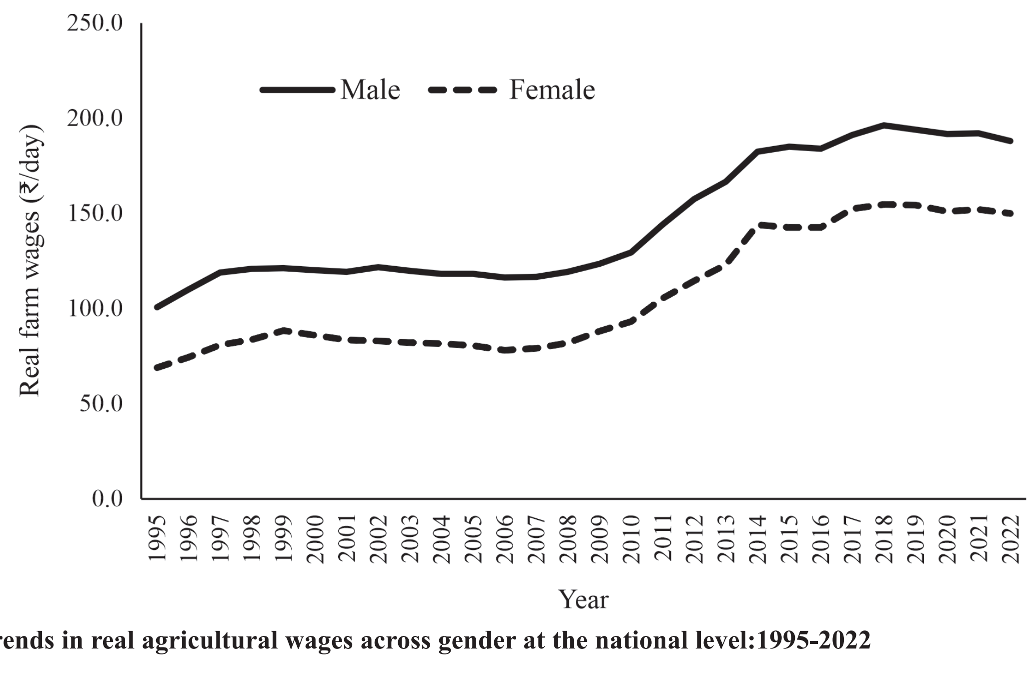

Figure 1 Trends in real agricultural wages across gender at the national level:1995-2022

Table 1. Growth in real agricultural wages across gender at national level : 1995-2005

Per cent

Period	Male	Female
1995-2006	1.22	1.04
2006-2014	5.12	7.03
2014-2022	0.33	0.45

from ₹ 100 to ₹ 116 at the annual growth of 1.22 per cent for male labour and from ₹ 68 to ₹ 78 at the growth rate of 1.04 per cent for female labour at the national level (Table 1). The male labour earned signficiantly higher wages as compared to the female counterparts.

After almost a decade of stagnation, the real farm wages witnessed a sharp increase between 2006 and 2014. During this period, these wages for male and female labours increased at the annual growth rate of 5.12 per cent and 7.03 per cent, respectively. A relatively higher growth in the wages for female labours as compared to male labours indicates a narrowing down of the disparity in their wages. One of the major reasons behind the sharp increase in real agricultural wages was the launching of MGNREGS, during the period 2006-2008 (Gulati et al., 2014; Chand and Srivastava, 2014). The MGNREGS pushed agricultural wages by either creating physical labour scarcity for agriculture, particularly during the peak agricultural seasons or raising reservation wages of the farm labours (Chand and Srivastava, 2014; Saini et al., 2020). These evidences show that MGNREGS served its intended purpose of improving the income of wage-earners in the rural areas by breaking the long stagnation in their wages. However, such outcomes have definite implications for agriculture as increased wages for farm labours directly contribute to the cost inflation. For negating possible adverse effects of social welfare programs like MGNREGS on farm profitability, it is essential to push labour-saving technologies to manage the physical scarcity of labour for farm operations and improve agricultural productivity to absorb the higher wages.

In addition to the impact of MGNREGS on agricultural wages, there existed a food-wage spiral in India such that the inflation in food price and agricultural wage growth impacted each other bidirectionally (Saini et al., 2020). Between July 1998 and December 2006, the food price inflation and nominal wage growth had a nearly equally strong impact on each other.

The real agricultural wages reached a plateau in 2014 and are stagnant since then for both male and female labours. The estimated growth in real wages for male and female labour at the national level was 0.33 per cent and 0.45 per cent during 2014 to 2022, respectively (Table 1). No structural break was observed in the real wages at the aggregate level on account of lockdown imposed to check COVID infection in 2020.

The trajectory of real wages followed a similar path for the major farm operations. Figure 2 presents the gender disaggregated trends in real wages for sowing and harvesting operations at the national level. The male labours earned significantly higher wages as compared to female labours for both of these farm operations throughout the period under consideration.

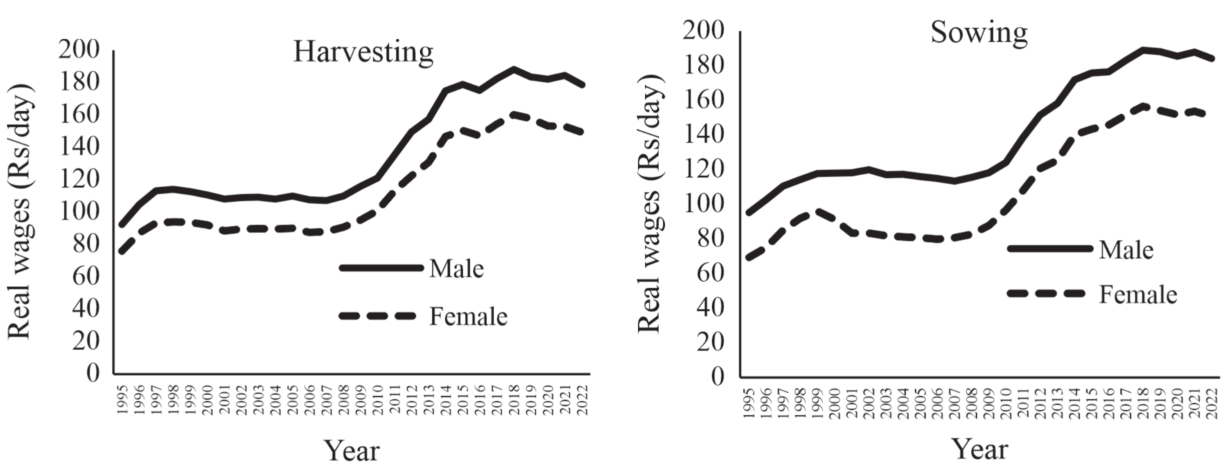

Figure 2 Trends in real wages for sowing and harvesting operations at national level

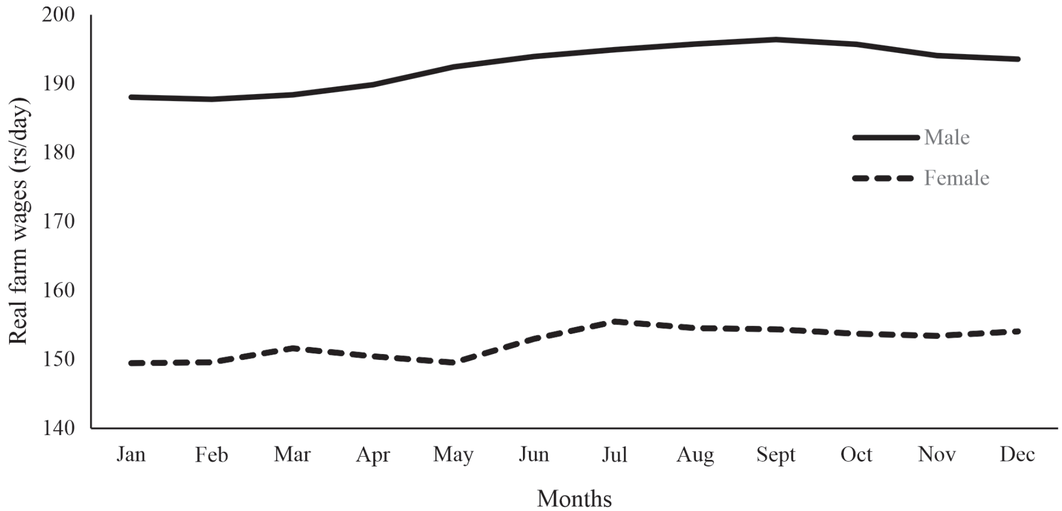

Figure 3 Intra-year variations in real agricultural wages across gender in India

Seasonality in real agricultural wages

The agricultural wages in India exhibit seasonality due to the nature of agricultural activities, crop cycles, and labour demand. Figure 3 shows the intra-year variation in real agricultural wages in India during the triennium ending (TE) 2021. The agricultural wages for male labours were found higher in the months of March-April, June-July, and September. This could be because March-April is the harvesting season for wheat, June-July is the sowing season for paddy, and September is the harvesting season for paddy. In the case of female, agricultural wages were higher in June-July, which is the sowing season for paddy. For the months of March, April, and May, wages for female labours were found lower. Overall, the evidences revealed the presence of intra-year variation or seasonality in the agricultural wages for male and female labours.

The seasonality in agricultural wages has been tested using a combined seasonality test for the major farm operations like harvesting, sowing, and ploughing at the national as well as state level. Table 2 presents the results of the seasonality test. The coefficients of seasonality test were found to be significant, and it was one for all the cases. This validated the presence of seasonality in agriculture wages across gender, farm operation and the state.

Inter-state variations in real agricultural wages in 2021

The agricultural wages have shown a significant variation across different states of India for several reasons, such as regional agricultural practices, cropping patterns, labour demand and supply dynamics, socio-economic conditions, government policies, etc. Figure 4 compares the real agricultural wages of male and female labours across the states in 2021. Among the states, agricultural wages were highest in Kerala for both male and female labours in 2021. The higher wages in Kerala might be due to the cultivation of high-value crops like plantation crops, which require skilled labour. As education level in the state is higher, the native workfore look for employment in the non-agricultural sectors or demand higher wages for farm operations. Additionally, the collective bargaining power of workers along with supply shortages of labour are considered to be the major drivers of higher wages in the state as compared to other regions of the country (Indira Devi, 2012). Kerala is followed by Himachal Pradesh, Tamil Nadu, Haryana, and Punjab in terms of farm wages. On the other hand, comparatively lower agricultural wages have been reported in states like Gujarat, Madhya Pradesh, Odisha, etc. Further, there exists a wide variation in the farm wages of male and female in all the states except in Haryana, Rajasthan, and Gujarat.

Impact of MGNREGS and COVID-led lockdown on farm wages at national level

The graphical analysis has revealed a structural change in agricultural wages during 2006, which coincided with the implementation of MGNREGS (Figure 1). Further, during the lockdown, agricultural wages were

Table 2 The results of seasonality test in real agricultural wages in states of India

State	Harvesting				Sowing				Ploughing			
	Male		Female		Male		Female		Male		Female	
	T	p	T	p	T	p	T	p	T	p	T	P
Andhra Pradesh	1	***	1	***	1	***	1	***	1	***	1	***
Assam	1	***	1	***	1	***	1	***	1	***		
Bihar	1	***	1	***	1	***	1	***	1	***		
Gujarat	1	***	1	***	1	***	1	***	1	***	1	***
Haryana	1	***	1	***	1	***	1	***	1	***	1	***
Himachal Pradesh	1	***	1	***	1	***	1	***	1	***		
Jammu & Kashmir	1	***	1	***	1	***			1	***		
Karnataka	1	***	1	***	1	***	1	***	1	***	1	***
Kerala	1	***	1	***	1	***	1	***	1	***		
Madhya Pradesh	1	***	1	***	1	***	1	***	1	***	1	***
Maharashtra	1	***	1	***	1	***	1	***	1	***	1	***
Manipur	1	***	1	***	1	***	1	***	1	***	1	***
Meghalaya	1	***	1	***	1	***	1	***	1	***	1	***
Odisha	1	***	1	***	1	***	1	***	1	***	1	***
Punjab	1	***	1	***	1	***	1	***	1	***	1	***
Rajasthan	1	***	1	***	1	***	1	***	1	***	1	***
Tamil Nadu	1	***	1	***	1	***	1	***	1	***		
Tripura	1	***	1	***	1	***	1	***	1	***	1	***
Uttar Pradesh	1	***	1	***	1	***	1	***	1	***	1	***
West Bengal	1	***	1	***	1	***	1	***	1	***	1	***
All-India	1	***	1	***	1	***	1	***	1	***	1	***

T: Test result, p: probability; *** Significant at 1% level, MA means moving average, AR means autoregressive

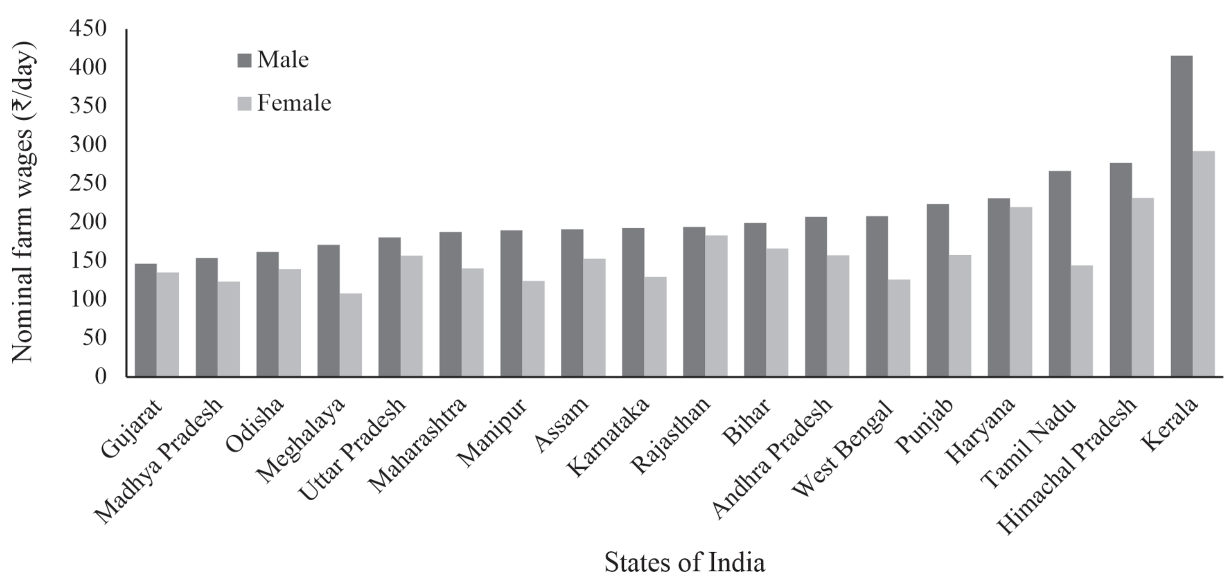

Figure 4 Inter-state variation in agricultural wages (at nominal prices) in 2021

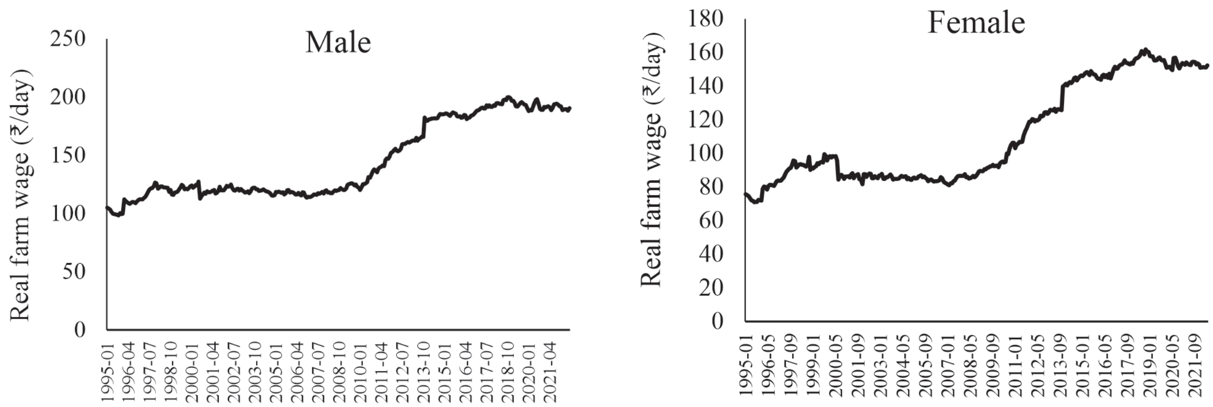

Figure 5 Trends in deseasonalised monthly real agricultural wages for male and female labours in India :1995-20

expected to decline due to increased labour supply due to reverse migration. The impacts of MGNREGS and lockdown on farm wages were assessed using the ARIMA-Intervention model. The earlier analysis had suggested the presence of seasonality in monthly wage series. In order to better evaluate the underlying trends and patterns, the data was de-seasonalised or seasonally adjusted to remove the impacts of seasonality, using the seasonality index with the help of R-studio. The seasonal analysis is valuable for understanding cyclical patterns and making decisions that take seasonality into account. The de-seasonalized data enables a more precise analysis and forecasting and offers a clearer understanding of the underlying trends. The de-seasonalised series of real farm wages for male and female labours is presented in Figure 5.

For analyzing the impact of MGNREGS and lockdown on wages, the first best-fitted ARIMA model was identified using R-studio, and then intervention analysis was performed in SAS software. The intervention points taken were 2006 and 2020, in which the MGNREGS (step intervention) was initiated and the lockdown due to COVID-19 (pulse intervention) was imposed, respectively. The MGNREGS is a welfare scheme introduced by the Government of India in February 2006, which has taken a grassroots approach to employment generation. It gives a legal guarantee of 100 days of wage employment in a financial year to adult members of a rural household who demand employment and are willing to do unskilled manual work. The MGNREGS has been depicted as a 'step intervention' in the model because the effect of this intervention is carried forward over time. The lockdown to curb the COVID pandemic has been used as a 'point intervention' as it was a sudden measure without a step effect. The models were estimated separately for three farm operations (harvesting, sowing, ploughing), aggregate level, and gender category.

The estimated impact parameter (ω) for MGNREGS was found to be positive and significant in all the models (Table 3). Further, the slope parameter (δ) was close to one, except in the model for female (sowing), which indicates that the impact of MGNREGS increased over time. These results were consistent for all farm operations and gender categories. The real wage rates have increased substantially during the post-MGNREGS period (2005-06 to 2010-11) as compared to the pre-MGNREGS period (2000-01 to 2005-06) for both male and female agricultural laborers in all the major farming operations (Deb et al., 2014).

In the case of lockdown, the impact parameters (have been found negative but insignificant in the cases, except female (sowing). This implies that the lockdown did not exert any significant impact on agricultural wages at the macro level. This could be due to the fact that after few initial days of lockdown, announced on March 24, 2020, the government granted relaxation for the activities related to farming and allied sector to facilitate unhindered farm activities (PIB, 2020). This implies that disequilibrium in labour market caused due to COVID-led lockdown was short-lived with no signficiant effect on agricultural wages.

Impact of MGNREGS and lockdown on agricultural wages in Punjab and Bihar

The farmers of the state of Punjab heavily depends on

Table 3 Estimated coefficients of ARIMA-intervention models at the national level in India

Model parameter	Overall		Harvesting		Sowing		Ploughing
	Male	Female	Male	Female	Male	Female	Male
MA 1	-	0.08 (0.05)	-	0.09 (0.05)	-	-	-
MA 2	-	-		0.15** (0.05)	-	-	-
AR 1	-	-	-	-	-0.03 (0.05)	-	-
Covid (ω)	-1.38 (1.4)	-0.43 (1.2)	-1.3 (1.5)	-0.7 (1.5)	-0.05 (1.63)	-6.6*** (1.46)	-1.1 (1.9)
MGNREGS (ω)	1.78** (0.6)	1.3** (0.45)	1.06* (0.5)	0.88* (0.35)	0.86* (0.46)	5.4** (1.9)	1.9* (0.8)
MGNREGS(δ)	0.97*** (0.01)	0.97*** (0.009)	0.98*** (0.008)	0.98*** (0.07)	0.99*** (0.008)	-0.5* (0.2)	0.97*** (0.01)
Model	Lock down: March/2020 + MGNREGS: January/ 2010/(1) + I(1) NOINT	Lock down: April/2020+ MGNREGS: January/ 2010/(1) + IMA(1,1) NOINT	Lock down: March/ 2020 + MGNREGS: April/ 2008/(1) + I(1) NOINT	Lock down: April/2020 + MGNREGS: April/ 2008/(1) + IMA(1,2) NOINT	Lock down: April/2020 + MGNREGS: April/2008 + IAR (1,1) NOINT	Lock down: May/2020 + MGNREGS: June/2010/1) + I(1) NOINT	Lock down: March/2020 + MGNREGS: June/2010/1) + I(1) NOINT

MA: Moving average value, AR: Autoregressive value
*Figures within the parentheses are standard errors

the migrated labourers from Bihar for their agricultural operations. During lockdown to curb the COVID, the movement restrictions created labour scarcity for undertakingfarm operations like harvesting wheat and transplanting paddy. Thus, the wages were expected to rise in the state during the lockdown period. On the other hand, due to reverse migration and movement restrictions, labour supply in the states like Bihar increased, which was expected to reduce wages. It is, therefore, imperative to assess the impact of the pandemic in the labour-surplus (Bihar) and labour-scarce (Punjab) states. The ARIMA-intervention model was used to assess this impact. As the model allows more than one intervention, the MGNREGS intervention was also included in the model to capture its impact on the wages. The results of the models, fitted separately for male men and female women labours, are presented in Table 4.

In the case of Punjab, the impact parameter (ω) for MGNREGS was found positive and significant with slope parameter (δ) close to one for the male agricultural labourers. This indicates a positive and significant impact of MGNREGS on the wages of male agricultural labourers, which increased over time. For the female labourers, the impact of MGNREGS was not found significant. The impact parameter for the Lockdown was found negative and insignificant for both Male and Female labourers, which implies that the COVID-19-led lockdown did not adversely affect the wages in the state of Punjab .

In Bihar, the estimated coefficients of impact parameter (for MGNREGS were positive and significant for both male men and female labourers, indicating a significant role of MGNREGS in increasing wages. The impact parameter for the Lockdown was found insignificant, which implies that the Lockdown did not significantly affect the agricultural wages in Bihar. Overall, the results have indicated that MGNREGS led to a rise in wages and the Lockdown to curb COVID did not have a significant effect on wages in both labour-surplus and labour-scarce states under study.

Conclusions

This study has examined the trajectory of agricultural wages and has assessed the impact of MGNREGS and

Table 4 Impact of Lockdown and MGNREGS on farm wages in Punjab and Bihar

Model parameter	Punjab		Bihar	
	Male	Female	Male	Female
MA 1	0.3**	-	-1.3***	0.01
	(0.14)		(0.06)	(0.05)
MA 2	-	-	-0.95***	-
			(0.06)	
AR 1	0.01	-0.04	-1.3***	-
	(0.15)	(0.05)	(0.04)	
AR 2	-	-	-0.97***	-
			(0.04)	
Covid ()	-2.1	-0.51	-1.8	-1.2
	(4.1)	(2.2)	(1.5)	(1.5)
MGNREGA ()	1.8*	-1.1	4.04*	4.03*
	(0.9)	(0.9)	(2.1)	(1.9)
MGNREGA (d)	0.9***	0.97***	0.4	0.66**
	(0.01)	(0.03)	(0.4)	(0.22)
Model	Lockdown: March/2020 + MGNREGS : April/2008 + ARIMA (1,1,1) NOINT	Lockdown: March/2020 + MGNREGS : April/2008 + IAR (1,1) NOINT	Lockdown: April/2020+ MGNREGS : June/2009 + ARIMA (2,1,2) NOINT	Lockdown: April/2020+ MGNREGS : June/2009 + IMA (1,1) NOINT

MA:Moving average value, AR: represents Autoregressive value
*Figures within the parentheses are standard errors

COVID-led lockdown on agricultural wages. Since 1995, the real agricultural wages had witnessed a decade of stagnation followed by a sharp rise till the year 2014. The MGRNEGS contributed significantly to the increase in real agricultural wages during 2006-2014 either by creating physical scarcity of labour for farm operations during peak agricultural season or by influencing the reservation wages of casual labour. Although wage increase is desirable for the wage-earners, it directly contributes to cost inflation. The adverse effects of wage increase on farm profitability can be countered by accelerating adoption of labour-saving technologies (to manage phsycial scarcity of labour) and improving agricultural productivity (to absorb the higher wages). Since 2014, the real agricultural wages have remained stagnant for both male and female labours. The study has revealed intra-year variability and disparity in agricultural wages across the states and gender.

The ARIMA-intervention modelling has confirmed that the imposition of nation-wide lockdown to check COVID infections, did not exert any significant impact on the agricultural wages. This could be due to the fact that after a few initial days of lockdown, the government granted relaxation for the activities related to agriculture and allied sector. This implies that disequilibrium in labour market caused due to COVID-led lockdown was short-lived with no signficiant effect on agricultural wages.

Acknowledgment

This paper is a part of the MSc thesis of the first author submitted to the Post Graduate School of ICAR-Indian Agricultural Research Institute (IARI), New Delhi.

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Received 4 October 2023 Accepted 5 February 2024

Agricultural Economics Research Review 2024, 37 (1), 13-34
DOI: 10.5958/0974-0279.2024.00007.3

Exploring carbon dioxide emissions and their drivers in global leading economies – A Panel vector autoregression perspective

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Abstract This study delves the intricate interplay between carbon dioxide (CO_2) emissions and economic development in the top 20 CO_2-emitting nations from 2011 to 2021. By examining the influential factors such as Gross Domestic Product (GDP), Gross Fixed Capital Formation (GFCF), Temperature Change (TC), and Urbanization (UPop), the study unravels their profound impact on CO_2-emissions. The study begins with testing the stationarity of its variables, finding that they become stationary after first-order differencing. The cross-section dependence test highlights the shared common factors among observations. Although the study initially seeks long-term equilibrium relationships, the findings don't strongly support this. Consequently, the focus shifts to examining short-term dynamics through first-order differences. The study has employed Panel VAR Model to balance temporal dependencies and model simplicity. It has found that lagged CO_2-emissions [d(CO_2 (-1))] show a significant and positive association with current CO_2-emissions , while a two-period lag [d(CO_2 (-2))] is not significant, suggesting an immediate CO_2 -impact. The GDP has been found negatively related to CO_2-emissions, indicating increased GDP leads to slight emission-reduction. The GFCF has shown a positive link, emphasizing capital investments' emission impact. The temperature change (TC) has shown a nuanced relationship, with short-term increases driving emissions. The Urbanization (UPop) consistently raises CO_2-emissions. The impulse response functions (IRFs) have visually illustrated CO_2 responses to standard deviation shocks in GDP, GFCF, TC, and UPop, revealing complex relationships over time. The variance decomposition analysis has revealed strong autocorrelation in economic variables, indicating that past values strongly predict future behaviour. The Granger-causality tests have established significant relationships, showing GDP and GFCF causing CO_2-emissions, emphasizing economic growth's impact. The UPop drives CO_2-emissions, reflecting urbanization challenges. However, reverse causality and the TC-emissions link lack clear statistical significance. These findings suggest the policymakers to prioritize green investments, sustainable practices, urban planning, climate-resilient policies, international cooperation, carbon pricing mechanisms, and public awareness. These multifaceted strategies would ensure equilibrium between economic growth and environmental sustainability through addressing the intricate dynamics of emissions while emphasizing the need for global collaboration.

Keywords CO_2-emissions, Panel cross-dependence, Panel vector autoregression, gross domestic product, gross fixed capital formation, temperature change, urbanization

JEL codes B22, C33, O44, Q53

Introduction

The challenge of balancing carbon dioxide (CO_2) emissions and economic development is a critical issue in the 21st century. CO_2-emissions have become a central concern due to their role in global climate change, leading to environmental, social, and economic consequences. These emissions result from human activities such as burning fossil fuels, deforestation etc. They trap heat in the Earth's atmosphere, leading to global warming, which, in turn, causes disruptions in the ecosystem (Nunes, 2023). Thus, CO_2-emissions must be reduced to mitigate climate change's adverse impacts, safeguard human health, stabilize economies, and promote sustainable resource management. Historically, economic growth was closely linked to increased energy consumption and, consequently, higher emissions. This connection is captured by Environmental Kuznets Curves (EKC), which show that emissions initially rise with economic growth but eventually decline beyond a certain income threshold (Ekins, 1997; Hiroyuki, 2012; Apergis, 2016). However, this relationship is nuanced, as economic development can either exacerbate emissions or facilitate their reduction. So, rapid industrialization and energy use create a positive feedback loop, causing emissions to rise. The economic growth, driven by carbon-intensive industries, often leads to higher CO_2-emissions.

Understanding the determinants for CO_2-emissions is paramount for achieving a harmonious equilibrium between economic growth and environmental sustainability. These determinants encompass a spectrum of factors, including Gross Domestic Product (GDP), Gross Fixed Capital Formation (GFCF), temperature fluctuations, and shifts in urban population. Each of these elements exert a profound influence on a nation's carbon emissions trajectory while also shaping its economic development too. The GDP, often regarded as the key indicator of economic prosperity, is intricately linked to energy consumption and CO_2-emissions (Muhammad et al., 2023). As economies expand, their energy demands tend to surge, with a significant portion sourced from the fossil fuels. This correlation underscores the imperative of decoupling economic growth from CO_2-emissions through cleaner technologies and enhanced energy efficiency. The GFCF reflects investments in infrastructure, machinery, and technological advancements within a nation. A higher value of GFCF often signals increased industrialization and construction, potentially resulting in heightened energy usage and CO_2-emissions. Striking a balance between investment and CO_2-emissions becomes pivotal for fostering sustainable development. The temperature fluctuations exert a direct impact on energy requirements and these emissions. A comprehensive understanding of these temperature-driven variations is indispensable for adapting to evolving climate conditions and building resilient energy systems. The escalating proportion of urban residents in a country is a global phenomenon. The urban areas are typically characterized by heightened transportation needs, energy-intensive buildings, and concentrated industrial activities. So, promotion of sustainable urban planning emerges as vital strategies for mitigating CO_2-emissions tied to urban expansion (FAO, 2017; Petar et al., 2020).

A perusal of Figure 1 reveals that CO_2-emissions are a critical global issue, and the top 20 countries are led by China with 1386.48 Mt, followed by India with 517.05 Mt and the United States with 475.57 Mt and other countries exhibit significant disparities in contributions to emissions. These emissions stem from a multitude of factors - rapid industrialization being a driving force behind these soaring emissions. The industrialization though brings economic growth, job opportunities, and improved living standards, often comes at the cost of increased emissions (Jiao et al., 2022). The developing nations like China and India have witnessed unprecedented industrial growth in recent decades, leading to a surge in. These nations have faced the challenge of balancing their economic aspirations with environmental concerns. The reliance on fossil fuels is another major contributor to high CO_2-emissions. While they have powered industrialization and modernization, they release significant amounts of CO_2 when burned. The USA and Russia, among others, have substantial reserves of these fossil fuels and rely on them for energy production and transportation (Friedlingstein et al., 2020). The energy-intensive industries are a crucial source of emissions. Manufacturing, heavy machinery, and construction are energy-hungry sectors that often utilize fossil fuels extensively and they contribute significantly to country's carbon footprints. Energy production, including electricity generation, is also a major contributor to CO_2-emissions. The coal-fired power

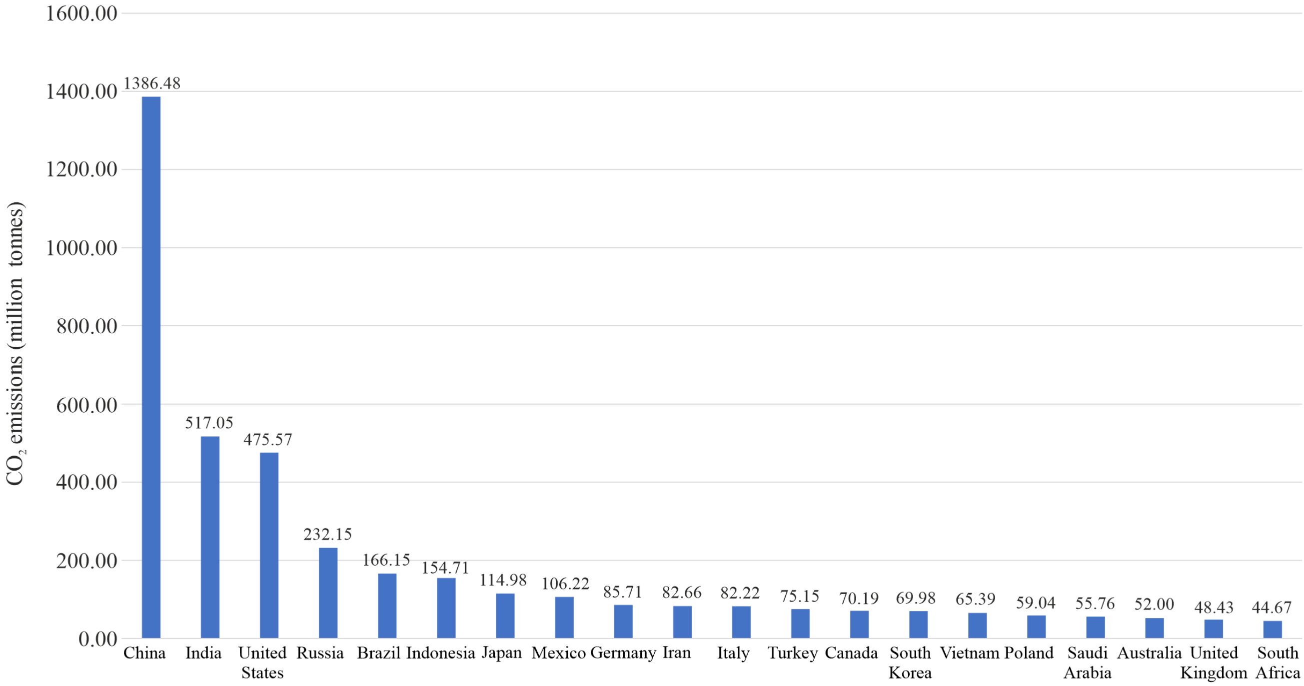

Figure 1 Country-wise CO_2 emissions (pre and post-production) during TE 2021

plants provide a cheap source of energy, but emit large quantities of CO_2. So, transition towards cleaner energy sources viz., natural gas, nuclear, and renewables is essential to reduce emissions from this sector (Ministry of Coal, 2021).

The transportation sector is another significant source of CO_2-emissions. The widespread use of gasoline and diesel-powered vehicles in countries like USA and Russia leads to substantial CO_2-emissions. Development of sustainable transportation solutions such as electric vehicles and improved public transit systems is vital in mitigating these emissions (Sajede et al., 2022). Additionally, agriculture expansion results in the clearing of forests and the release of stored carbon. These activities not only emit CO_2 directly but also disrupt natural carbon sinks, exacerbating the problem. The top 20 countries with significant CO_2-emissions often share common reasons for their high carbon footprints, which are typically driven by factors such as rapid industrialization, heavy reliance on fossil fuels, energy-intensive industries, and more (Asif et al., 2022; Inekwe et al., 2020).

Several researchers have conducted numerous empirical studies (Table 1) aimed at unravelling the intricate interplay among critical factors such as economic growth, energy consumption, and their impact on environment. Within the extensive body of existing literature, two major strands of research have emerged. Firstly, there are studies that delve into relationship between economic growth and environmental degradation, often referred to as the Environmental Kuznets Curves (EKC) hypothesis. Secondly, earlier studies focused only on relation between economic growth and CO_2-emissions. So, this study stands as a valuable contribution by bridging this gap through considering a higher number of determinants for CO_2-emissions and thus, broaden the scope of inquiry to offer a more holistic view of complex interactions shaping our environment and economies.

In addition to the aforementioned studies, Chontanawat (2020) found a long-term and two-way causal relationship between energy consumption and CO_2-emissions in the ASEAN. Gorus et al. (2019) discovered variations in the causal relationship between energy consumption and economic growth among eight countries in the Middle East and North Africa (MENA) region. They observed a one-way Granger causality in the short term, while in the medium- and long-terms, there was a feedback effect between them. In contrast to the studies on energy consumption leading to carbon

Table 1 Some recent studies on interdependence of CO_2-emissions and economic growth using Panel VAR approach

Authors	Period	Countries	Relationship
Magazzino (2014)	1971-2007	ASEAN-6 countries	GDP $\rightarrow$ CO_2 GDP $\leftarrow$ EC
Antonakakis et al. (2017)	1971-2011	106	GDP $\leftrightarrow$ CO_2 GDP $\leftrightarrow$ EC EC $\rightarrow$ CO_2
Magazzino (2017)	1960-2013	19 APEC	GDP $\rightarrow$ CO_2 GDP $\neq$ EC
Acheampong et al. (2018)	1990-2014	116	GDP $\leftrightarrow$ CO_2 GDP $\leftarrow$ EC EC $\leftarrow$ CO_2 EKC validity
Ozcan et al. (2019)	2000-2014	35 OECD	GDP $\rightarrow$ CO_2 GDP $\leftrightarrow$ EC EC $\rightarrow$ CO_2
Huanyu et al. (2022)	2003-2017	30 provinces & municipalities in China	Financial development $\rightarrow$ CO_2 GDP $\rightarrow$ CO_2 EC $\rightarrow$ CO_2 Urbanization $\rightarrow$ CO_2
Leonidas (2022)	1990-2015	113	GDP $\rightarrow$ CO_2 GDP $\rightarrow$ EU EU $\leftrightarrow$ CO_2

Notes ASEAN - Association of Southeast Asian Nations; APEC - Asia-Pacific Economic Cooperation; OECD - Organization for Economic Co-operation and Development; EC - Energy consumption; EKC - Environmental Kuznets curve, EU – Energy Use; $\rightarrow$ indicates unidirectional relationship, $\leftrightarrow$ indicates bi-directional relationship, $\neq$ - indicates no causal relationship

emissions, Muhammad et al. (2020) found that CO_2-emissions had a significant and direct impact on energy consumption in groups of developed, emerging, Middle East and North Africa (MENA) countries. The increase in CO_2-emissions was found to increase energy consumption significantly in these regions. Wu et al. (2020) studied the relationship between energy consumption, environmental regulation, and carbon emissions in China. Using spatial Durbin models and dynamic threshold panel models, they found that energy consumption significantly promotes carbon emissions in the eastern, central, and western regions of China. Gu et al. (2019) discovered an inverted U-shaped relationship between energy consumption and carbon emissions during technological progress. They observed that when technological development is low, energy consumption promotes carbon emissions, whereas at high levels of technological development, energy consumption curbs carbon emissions.

Several researchers have employed various methods to explore the relationship between urbanization and carbon emissions across different regions, yet a widely accepted consensus has remained elusive. Wang et al. (2020) conducted a study on Asia-Pacific Economic Cooperation (APEC) member states using Dynamic Seemingly Unrelated Regressions (DSUR) and found that urbanization increased energy demand and facilitated the flow of goods and services, resulting in a significant positive impact on CO_2-emissions. Mahmood et al. (2020), focusing on Saudi Arabia, reached a similar conclusion, identifying a short-run and cointegrating relationship between urbanization and carbon emissions and attributing urbanization to environmental degradation through increased carbon emissions. In contrast, Muhammad et al. (2020) discovered an inverted U-shaped relationship between urbanization and carbon emissions in high-income groups, with a U-shaped relationship observed in other income level groups. Liu et al. (2018), in their study on China utilizing Autoregressive Distributed Lag (ARDL) techniques, also found a positive impact of urbanization on carbon emissions. Yao et al. (2021)

Table 2 List of selected variables

Variable name	Unit of measurement	Definition
CO_2-emissions	Tonnes	The carbon emissions released from pre and post-production processes
GDP	US$	Economic growth of a country in real terms
GFCF	US$	Measure the level of investment in the economy
UPop	%	Proportion of urban population in totalpopulation
TC	^oC	Annual temperature change on land

further disaggregated urbanization into three dimensions—population urbanization, economic urbanization, and land urbanization—and examined their impact on carbon emissions across 351 cities in China. They found heterogeneous effects of urbanization across different types of cities, including small, medium-sized, large, and megacities.

The widespread utilization of the Panel VAR method in the aforementioned studies underscores its prevalence in analyzing the determinants for CO_2-emissions. This approach offers a robust framework for analyzing cross-country and time-series variations, modelling interdependencies, conducting dynamic analyses, testing causality, and providing policy insights. By utilizing a panel of countries or regions, these studies facilitate comparative analyses and contribute to a comprehensive understanding of complex dynamics within the realm of environmental economics and sustainability research (Linus and Niraj, 2022; Paibi et al., 2022). The research gap addressed by this study lies in the exploration of CO_2-emissions and their drivers across the top 20 countries, using a Panel Vector Autoregression (VAR) model.

While numerous studies have examined CO_2-emissions and their determinants, only a few have specifically focused on the top emitters and employed advanced econometric techniques like Panel VAR. The specificity of this paper is in offering a comprehensive analysis of CO_2-emissions dynamics in the world's leading economies, providing insights into the most influential determinants and their temporal dynamics. By leveraging the Panel VAR model, the study aims to identify key drivers of CO_2-emissions, quantify their impacts, and understand how these relationships evolve over time. Furthermore, the research rationale lies in empowering policymakers with evidence-based insights to develop targeted strategies for mitigating CO_2-emissions and addressing climate change effectively. This study contributes to the literature by offering a nuanced understanding of CO_2-emissions dynamics in the context of the top 20 CO_2-emitting countries and providing actionable insights for policy formulations and international collaborations on climate change mitigation efforts.

Data and Methodology

This paper analyzes a panel dataset comprising top 20 CO_2-emitting countries over the period 2011 to 2021 (Figure 1). The dataset incorporates several key variables (Table 2), viz., CO_2-emissions, which represent the volume of carbon dioxide released into the atmosphere, economic growth (GDP), investment in fixed assets (GFCF), urbanization expressed as the proportion of urban population (UPop) in total population, and temperature change (TC), which reflects alterations in climate conditions (Hannah et al., 2020; Griffin et al., 2023). These selected variables are crucial for analyzing the determinants of CO_2-emissions, as complex interactions can be assessed between economic activity, investment, urbanization, climate variability, and CO_2-emissions across different countries over time. The Panel VAR approach allows the estimation of dynamic relationships between these variables, capturing both short-term and long-term effects, providing insights into the underlying drivers of CO_2-emissions in the top 20 countries and informing policy interventions aimed at mitigating environmental impact while promoting sustainable economic development. The data are diligently sourced from the Official website of the FAOSTAT database for this study (2011 to 2021).

Panel unit root tests

Before applying the Panel VAR for analysis, the initial step involves assessing the data properties for unit root. The panel unit root tests have evolved into two generations. The first-generation tests, like the Lin, Levin, and Chu (LLC) test and Fisher Augmented Dickey-Fuller (ADF) test, assume independence among individual units within the panel. The second-generation tests, viz., Cross-Sectionally Augmented Dickey-Fuller (CADF) and Cross-Sectionally Augmented Im, Pesaran, and Shin (CIPS) tests, developed by Pesaran (2007) and Moon and Perron (2004) consider cross-sectional dependence. The CADF test is represented by Eq. (1):

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \gamma_i \bar{Y}_{t-1} + \delta_i \Delta\bar{Y}_{t-1} + \varepsilon_{it} \quad \ldots(1)$$

where, $\bar{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{it}$; $\Delta\bar{Y}_t = \frac{1}{N}\sum_{i=1}^{N} \Delta\bar{Y}_{it}$; ε_{it} is the regression error

The CIPS test is given by Eq. (2):

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad \ldots(2)$$

where, $CADF_i$ represents the cross-section ADF statistic pertaining to the ith cross-sectional unit, obtained from t-ratio of β_i of Equation 4.

The null hypothesis (H_0) posits the existence of unit root, irrespective of the specific testing methods employed. In all instances, H_0 asserts that time series under examination is non-stationary at the level. The p-value plays a pivotal role in either rejecting or accepting this hypothesis. When the p-value falls below the 5 per cent significance level, it provides grounds for rejecting the H_0, (Jamel and Derbali, 2016). Conversely, if H_0 is upheld, it signifies panel data indeed demonstrates unit root at level, suggesting non-stationarity.

Panel Cross-sectional Dependence (CD) test

Breusch and Pagan (1980) asserted that neglecting to account for CD in data analysis can significantly distort research outcomes, potentially compromising validity of results. To address this concern, Pesaran (2004) introduced a CD test with improved performance in situations where the number of cross-sectional units (N) is large and the time dimension (T) is relatively small in panel data. This CD test operates on the principle that, when cross-sectional dependence exists, residuals will exhibit non-zero correlations, signalling the need to account for such dependence in analysis.

Considering a general panel data model: $Y_{it} = \mu_i + \beta_i X_{it} + \mu_{it}$

The CD statistic is derived as per Eq. (3):

$$\text{CD}=\sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i-1}^{N}\rho_{ij} \quad \ldots(3)$$

where, $$\rho_{ij} = \frac{\sum_{t=1}^{T} e_{it}e_{jt}}{\sqrt{\sum_{t=1}^{T} e_{it}^2}\sqrt{\sum_{t=1}^{T} e_{jt}^2}} \quad \ldots(4)$$

and e_{it} and e_{jt} are the residual values estimated by OLS estimation.

Pesaran (2021) showcased that CD test exhibits robust performance in small sample sizes. Here, H_0 posits absence of cross-sectional dependence, and if H_0 is rejected, it signifies the presence of cross-sectional dependence in data. This approach ensures that subsequent testing accounts for identified cross-sectional dependence, enhancing accuracy and reliability of results.

Panel cointegration test

Kao Residual Cointegration Test, Pedroni Residual Cointegration Test, and Westerlund ECM Panel Test are employed to examine stable long-run relationship between variables (Joakim, 2007). If these test statistics are non-significant at the chosen significance level, it suggests absence of cointegration among variables in panel data. The Pedroni Residual Cointegration Test offers various test statistics, viz., panel-panel, group panel, and augmented panel tests. The Westerlund Panel Test calculates four statistics, viz., Group Statistic (G_T Statistic), Average Statistic (G_A Statistic), Panel Statistic (P_T Statistic) and Pooled Statistic (P_A Statistic). The group statistic (G_T) is given by Eq. (5):

$$G_T = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\alpha_i}}{SE(\widehat{\alpha_i})} \quad \ldots(5)$$

where, 'N' represents the number of cross-sectional units (countries) in the panel data, $\hat{\alpha}_i$ represents the estimated coefficient for each individual unit, $SE(\hat{\alpha}_i)$ represents the standard error of the estimated coefficient for each individual unit.

The average statistic (G_A) is given by Eq. (6):

$$G_A = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\alpha_i}}{\widehat{\alpha_i}(1)} \quad \ldots(6)$$

where, $T\hat{\alpha}_i$ represents the t-statistic of the estimated coefficient for each individual unit, $\hat{\alpha}_i(1)$ represents the lagged value of the estimated coefficient for each individual unit.

The panel statistic (P_T) is given by Eq. (7):

$$P_T = \frac{(\hat{\alpha})}{SE\ (\hat{\alpha})} \quad \ldots(7)$$

where, $\hat{\alpha}$ represents the estimated coefficient for the panel as a whole, $SE\ (\hat{\alpha}_i)$ represent the standard error of the estimated coefficient for the panel as a whole.

The pooled statistic (P_A) is given by Eq. (8):

$$P_A = T(\hat{\alpha}) \quad \ldots(8)$$

where, $T(\hat{\alpha}_i)$ represents the t-statistic of the estimated coefficient for the panel as a whole.

Modified Wald test for groupwise heteroskedasticity

This test is used to detect the presence of heteroskedasticity in panel data models, particularly when there is a concern that variance of the error-terms may vary across different groups or entities within the panel. It is given by Eq. (9):

$$\text{Modified Wald test statistic} = \sum_{i=1}^{N_g} \frac{(\hat{\sigma}_i^2 - \hat{\sigma}^2)^2}{V_i} \quad \ldots(9)$$

where, N_g is the number of groups; $\hat{\sigma}_i^2$ is sample variance of residuals within i^th^ group; $\hat{\sigma}^2$ is estimated overall variance of residuals across all groups; V_i is the estimated variance of σ_i^2.

The test statistic follows a chi-squared distribution with K – 1 degrees of freedom under the null hypothesis of homoskedasticity across different entities within the panel. If the test statistic exceeds the critical value corresponding to the chosen significance level, then there is evidence to reject the null hypothesis of homoskedasticity in favour of the alternative hypothesis of heteroskedasticity.

Wooldridge test for autocorrelation

It is used to detect the presence of autocorrelation in the residuals of a panel data regression model. This is expressed by Eq. (10):

$$W = \frac{SS_e^2}{SS_e} \quad \ldots(10)$$

where, SS_e^2 = Squared sum of residuals across entities; SS_e = Sum of squared residuals across entities

Slope heterogeneity test

Further, relying on the assumption of a homogeneous slope without verification can lead to inaccurate estimations. So, heterogeneity of slope coefficients across different cross-sections was verified (Swamy, 1970; Hashem and Yamagata, 2008) through Equations (11) and (12):

$$\hat{\Delta} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \quad \ldots(11)$$

$$\hat{\Delta}_{adjusted} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right) \quad \ldots(12)$$

Panel VAR specification

This article employs Panel VAR (Love and Zicchino, 2006) to analyse dynamic interactions among multiple variables. It combines benefits of traditional vector autoregressive methods and panel data and thus, effectively addresses panel individual heterogeneity without the need for long-term time series data. This model treats all variables as endogenous, considering the impact of lagged variables on each other and is well-suited for studying macroeconomic dynamics and holds significance for examining economic issues across diverse regions or countries, making it a valuable tool for complex economic analyses. The derivation and construction of Panel VAR model is as follows:

First, we considered a set of time data variables Y_t, i.e.

$$Y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ \vdots \\ y_{nt} \end{bmatrix}, t = 1,2,3,\cdots,T \quad \ldots(13)$$

The VAR model with first-order lag of two variables is shown in Eq. (14):

$$\begin{cases} y_{1t} = c_1 + \varphi_{11}(1)y_{1,t-1} + \varphi_{12}(1)y_{2,t-1} + \varepsilon_{1t} \\ y_{2t} = c_2 + \varphi_{21}(1)y_{1,t-1} + \varphi_{22}(1)y_{2,t-1} + \varepsilon_{2t} \end{cases} \quad \ldots(14)$$

Then, re-writing Eq. (14) into matrix form, we could get expression (15):

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \varphi_{11}(1) & \varphi_{12}(1) \\ \varphi_{21}(1) & \varphi_{22}(1) \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \quad \ldots(15)$$

Let $Y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix}$, $C = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$, $\Phi_1 = \begin{bmatrix} \varphi_{11}(1) & \varphi_{12}(1) \\ \varphi_{21}(1) & \varphi_{22}(1) \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$, the matrix form of Equation (15) can be simplified as Eq. (16):

$$Y_t = C + \varphi_1 Y_{t-1} + \varepsilon_t \quad \ldots(16)$$

The VAR model with k-order lag of variables can be expressed by Eq. (17):

$$Y_t = C + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \Phi_3 Y_{t-3} + \cdots + \Phi_k Y_{t-k} + \varepsilon_t \quad \ldots(17)$$

where, $C = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_n \end{bmatrix}$ is intercept term vector, $\Phi_j = \begin{bmatrix} \varphi_{11}(j) & \varphi_{12}(j) & \cdots & \varphi_{1n}(j) \\ \varphi_{21}(j) & \varphi_{22}(j) & \cdots & \varphi_{2n}(j) \\ \vdots & \vdots & \ddots & \vdots \\ \varphi_{n1}(j) & \varphi_{n2}(j) & \cdots & \varphi_{nn}(j) \end{bmatrix}, j = 1,2,3,\ldots,k$ is the parameter matrix, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \vdots \\ \varepsilon_{nt} \end{bmatrix}$ is the random error column vector.

At this point, when we consider set of panel data Y_{it}, i.e.

$$Y_{it} = \begin{bmatrix} y_{1it} \\ y_{2it} \\ y_{3it} \\ \vdots \\ y_{nit} \end{bmatrix}, i = 1,2,3,\cdots,n; t = 1,2,3,\cdots,T \quad \ldots(18)$$

we could obtain a simplified matrix form of Panel VAR model with k-order lag of variables, as shown in Eq. (19), by introducing panel data into the above VAR model.

$$Y_{it} = C_i + \Phi_1 Y_{i,t-1} + \Phi_2 Y_{i,t-2} + \Phi_3 Y_{i,t-3} + \cdots + \Phi_k Y_{i,t-k} + \varepsilon_{it}$$

$$\text{where, } C_i = \begin{bmatrix} c_{1i} \\ c_{2i} \\ c_{3i} \\ \vdots \\ c_{ni} \end{bmatrix}, \Phi_j = \begin{bmatrix} \varphi_{11}(j) & \varphi_{12}(j) & \cdots & \varphi_{1n}(j) \\ \varphi_{21}(j) & \varphi_{22}(j) & \cdots & \varphi_{2n}(j) \\ \vdots & \vdots & \ddots & \vdots \\ \varphi_{n1}(j) & \varphi_{n2}(j) & \cdots & \varphi_{nn}(j) \end{bmatrix}, j = 1,2,3,\ldots,k, \varepsilon_t = \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \vdots \\ \varepsilon_{nit} \end{bmatrix}. \quad \ldots(19)$$

The final form of Panel VAR model was obtained by introducing individual fixed effect variables and time dummy variables, and simplifying the lag coefficient matrix, as shown below:

$$\Delta Ln(CO_{2it}) = C_{1i} + \alpha_{1i} + \delta_{1t} + \varepsilon_{1it} + \sum_{j=1}^{k} a_{1j} \Delta Ln(CO_{2i,t-j}) + \sum_{j=1}^{k} b_{1j} \Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} c_{1j} \Delta Ln(GFCF_{i,t-j}) + \sum_{j=1}^{k} d_{1j} \Delta Ln(UPop_{i,t-j}) + \sum_{j=1}^{k} e_{1j} \Delta Ln(TC_{i,t-j})$$

$$\Delta Ln(GDP_{it}) = C_{2i} + \alpha_{2i} + \delta_{2t} + \varepsilon_{2it} + \sum_{j=1}^{k} a_{2j} \Delta Ln(CO_{2i,t-j}) + \sum_{j=1}^{k} b_{2j} \Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} c_{2j} \Delta Ln(GFCF_{i,t-j}) + \sum_{j=1}^{k} d_{2j} \Delta Ln(UPop_{i,t-j}) + \sum_{j=1}^{k} e_{2j} \Delta Ln(TC_{i,t-j})$$

$$\Delta Ln(GFCF_{it}) = C_{3i} + \alpha_{3i} + \delta_{3t} + \varepsilon_{3it} + \sum_{j=1}^{k} a_{3j} \Delta Ln(CO_{2i,t-j}) + \sum_{j=1}^{k} b_{3j} \Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} c_{3j} \Delta Ln(GFCF_{i,t-j}) + \sum_{j=1}^{k} d_{3j} \Delta Ln(UPop_{i,t-j}) + \sum_{j=1}^{k} e_{3j} \Delta Ln(TC_{i,t-j})$$

$$\Delta Ln(UPop_{it}) = C_{4i} + \alpha_{4i} + \delta_{4t} + \varepsilon_{4it} + \sum_{j=1}^{k} a_{4j} \Delta Ln(CO_{2i,t-j}) + \sum_{j=1}^{k} b_{4j} \Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} c_{4j} \Delta Ln(GFCF_{i,t-j}) + \sum_{j=1}^{k} d_{4j} \Delta Ln(UPop_{i,t-j}) + \sum_{j=1}^{k} e_{4j} \Delta Ln(TC_{i,t-j})$$

$$\Delta Ln(TC_{it}) = C_{5i} + \alpha_{5i} + \delta_{5t} + \varepsilon_{5it} + \sum_{j=1}^{k} a_{5j} \Delta Ln(CO_{2i,t-j}) + \sum_{j=1}^{k} b_{5j} \Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} c_{5j} \Delta Ln(GFCF_{i,t-j}) + \sum_{j=1}^{k} d_{5j} \Delta Ln(UPop_{i,t-j}) + \sum_{j=1}^{k} e_{5j} \Delta Ln(TC_{i,t-j})$$

Here, 'j' is an optimal lag length of model. Before applying a Panel VAR model, selecting the appropriate lag order is crucial. The criteria viz., Coefficient of multiple determination, which measures the overall goodness of fit of the model and Hansen's J statistic, which assesses the model's validity and potential overfitting. Additionally, the MBIC (Modified Bayesian Information Criterion), MAIC (Modified Akaike Information Criterion), and MQIC (Modified Hannan-Quinn Information Criterion) were calculated, following the methodology proposed by Andrews and Lu in 2001 (Bauer, 2023).

The Panel VAR approach, while valuable for analyzing dynamic relationships among variables in panel data, is subject to several limitations. These include assumptions of linearity and homogeneity across individual entities, challenges in estimating models with a large number of variables or a small-time dimension, potential endogeneity issues, and difficulties in interpretation. Additionally, Panel VAR model requires a sufficient amount of data and assumes stationarity of variables over time. Despite these limitations, the Panel VAR model remain a useful tool for exploring dynamic interactions in panel datasets, provided researchers carefully consider their applicability and potential constraints.

Results and Discussions

Descriptive statistics

The descriptive statistics (Table 3) reveal significant insights that on an average, 71.12 percent of the population resides in urban areas, with a notable standard deviation of 15.97 per cent, indicating

Table 3 Descriptive statistics of selected variables

Variable	Mean	Std.Dev.	Min	Max
UPop (% UPop to total population)	71.12	15.97	31.02	92.97
CO_2-emissions (Mt)	192.09	292.79	31.77	1409.68
GFCF (million US$)	803287	1327017	36348	7497239
Real GDP (million US$)	3075468	4569672	135539	23315081
TC (°C)	1.287	0.5684	0.118	3.691

substantial variability in urbanization levels across countries. The CO_2-emissions average 192.09 Mt, but with a wide standard deviation of 292.79 Mt, underscoring diverse emissions levels influenced by industrialization and environmental policies. The GFCF averages US$803.29 billion, showing considerable variation with a standard deviation of US$1.33 trillion, reflecting differing investment patterns. The real GDP averages US$3.08 trillion, yet with a sizable standard deviation of US$4.57 trillion, indicating diverse economic outputs. The temperature change averages 1.287 °C, with a standard deviation of 0.5684 °C, suggesting varying climate impacts. These statistics collectively depict the complex economic, environmental, and developmental landscapes across the dataset, highlighting the challenges and opportunities for policy and sustainable development initiatives globally. Further, a visual inspection (Figure 2) of the log-series shows an upward trend for all variables.

Correlation matrix

The correlation matrix (Table 4) reveals several noteworthy findings among the variables (Magazzino, 2014). A strong positive correlation (0.822) between CO_2-emissions and UPop suggests that countries with higher CO_2-emissions tend to have higher UPop, possibly due to environmental impact of urbanization and industrialization. Similarly, CO_2-emissions are positively correlated with GFCF at 0.785, indicating that nations with more significant investments in fixed capital often produce higher emissions, likely as a result of industrial and infrastructural developments.

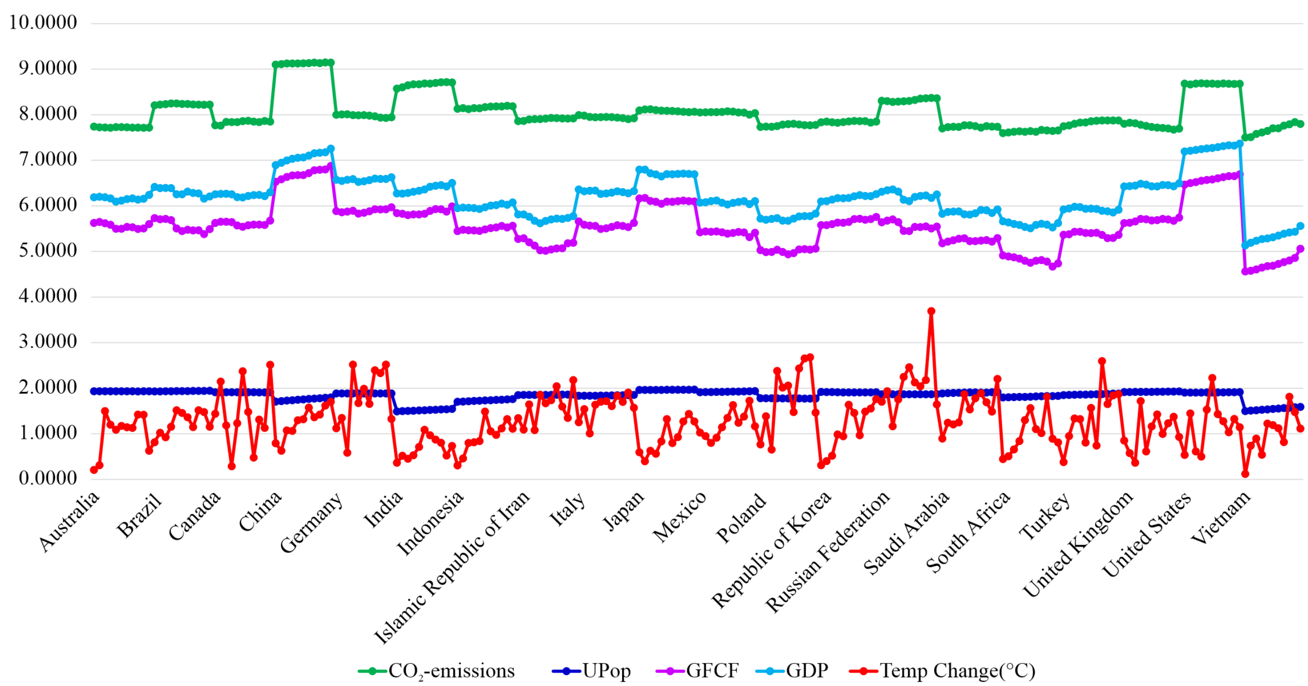

Figure 2 Trends in selected variables in selected countries

Table 4 Correlation matrix among selected variables

Variable	CO_2	UPop	GFCF	GDP	TC
CO_2	1.000				
UPop	0.822**	1.000			
GFCF	0.785**	0.608**	1.000		
GDP	-0.728**	0.706**	0.977**	1.000	
TC	0.545*	0.206	-0.075	-0.037	1.000

Note ** & * denote significance at 1 per cent and 5 per cent levels, respectively

Additionally, a negative correlation (0.728) exists between CO_2-emissions and GDP, indicating that economic growth is closely associated with increased carbon emissions. The positive correlation (0.545) between TC and CO_2-emissions indicates that countries experiencing more significant annual temperature changes tend to produce more CO_2. The strong positive correlation between GFCF and GDP (0.977) is primarily driven by capital formation in expanding productive capacity, improving productivity, and fostering economic growth. It reflects the idea that investment in capital assets is a key driver of economic development and higher GDP. The strong positive correlation between GFCF and GDP with urban population is driven by urban areas serving as economic hubs that attract investment, infrastructure development, and a skilled workforce, leading to higher economic activity and growth. However, it is interesting to note a slightly negative correlation (-0.075) between GFCF and annual TC, suggesting that more extensive capital formation might be linked to lower temperature changes, potentially due to increased efficiency and sustainable practices in advanced economies.

Panel unit root tests

The findings from both first-generation unit root tests (LLC and Fisher ADF) and second generation tests (CIPS and CADF) highlight that all the selected variables exhibit strong evidence of non-stationarity in level form (I(0)) (Table 5). But, after subjecting each variable to a first-order difference, all the data successfully passed unit root test and are found integrated with a first-order difference, making all sequences stationary. This crucially suggests that the initial non-stationarity observed in data can be eliminated by taking the first-order difference, rendering the data stable and this is the pre-requisite before estimating Panel VAR model (Acel et al., 2017).

Panel Cross-section dependence test

The panel cross-section dependence tests conducted using various statistical methods uniformly reject the H_0 of 'cross-sectional independence' and strongly indicate the presence of CD among the panel data, suggesting that observations are not independent of one another (Table 6). This implies existence of

Table 5 Panel Unit root tests of selected variables

Variables	1st Generation tests				2nd Generation tests			
	LLC		Fisher ADF		CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
log CO_2 emissions	-1.187	-6.388**	-1.341	-2.342*	-1.594	-2.773**	-1.342	2.610**
log GDP	-0.929	-6.794**	-0.842	3.207**	-1.180	-2.938**	-1.024	2.768**
log GFCF	-0.956	-5.748**	-1.277	1.936*	-1.071	-2.861**	-1.230	2.729**
log UPop	-0.770	-2.788**	-2.862	2.066*	-0.582	-2.902**	-1.992	-2.881**
log TC	-0.996	-5.882**	1.147	3.448**	-0.627	-3.286**	-1.719	-2.645**

Note ** & * denote significance at 1 per cent and 5 per cent levels, respectively

Table 6 Results of panel CD test

Test	Statistic	Prob
Pesaran's test	4.477	0.000
Friedman's test	35.727	0.035
Frees' test	4.110	Critical values from Frees' Q distribution at 1% = 0.465
Breusch-Pagan LM	508.902	0.000
Pesaran scaled LM	16.359	0.000

interdependencies or common factors shared across the dataset's cross-section, which is a crucial consideration when analyzing the data. Understanding and accounting for this CD is essential for the accurate and meaningful interpretations in panel data analysis (Cheng et al., 2007).

Panel Cointegration, Autocorrelation, Heteroskedasticity and slope Heterogeneity tests

The Kao Residual Cointegration test, Westerlund test (Variance ratio) and Westerlund ECM panel test concluded the absence of cointegration relationship among variables (Table 7). Further, the majority of multiple statistics (7 out of 11) under Pedroni Residual Cointegration test also concluded a no long-term equilibrium relationship among variables. Consequently, it is advisable to proceed with estimating first-order differences in the model, as it offers a more suitable approach for exploring the potential significant relationships between these variables. By differencing the data, we can better capture short-term dynamics, as cointegration relationship is not apparent (Acel et al., 2017). The Wooldridge test has demonstrated a test statistic of 45.831 and a probability value of 0.000,

Table 7 Results of Panel data sets: Cointegration test, Wooldridge test for Autocorrelation, Modified Wald test for groupwise heteroskedasticity and slope heterogeneity tests

Tests	Statistic	Prob	Weighted statistic	Prob
Cointegration tests				
Kao Residual Cointegration test (t statistic)	-1.389	0.083	—	—
Pedroni Residual Cointegration test				
Panel v-Statistic	-2.351	0.991	-3.174	0.999
Panel rho-Statistic	3.883	0.999	3.021	0.999
Panel PP-Statistic	-1.191	0.117	-5.574	0.000
Panel ADF-Statistic	-1.004	0.158	-4.385	0.000
Group rho-Statistic	5.074	1.000		
Group PP-Statistic	-8.490	0.000		
Group ADF-Statistic	-4.210	0.000		
Westerlund test (Variance ratio)	1.151	0.125		
Westerlund ECM panel test				
Gt (Z test)	0.700	0.758		
Ga (Z test)	2.901	0.998		
Pt (Z test)	0.655	0.744		
Pa (Z test)	-0.617	0.269		
Wooldridge test for autocorrelation F(1, 19)	45.831	0.000		
Modified Wald test for groupwise heteroskedasticity ($\chi^2(20)$)	2628.84	0.000		
Slope Heterogeneity tests				
$\hat{\Delta}$	2.257	0.024		
$\hat{\Delta}_{adjusted}$	3.348	0.001		

Table 8 Lag-order selection statistics for Panel VAR model estimation

lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	0.997	73.394	0.336	-256.943	-64.606	-142.715
2	0.998	81.921	0.307	-301.762	-73.968	-166.438
3	0.997	37.288	0.744	-183.558	-31.668	-102.983

indicating the presence of autocorrelation in the panel data. Furthermore, the Modified Wald test reveals a test statistic of 2628.84, with a probability value of 0.000, indicating the presence of significant group wise heteroskedasticity in the panel data. The significant and values suggest that there are meaningful and statistically significant variations in the determinants of CO_2-emissions operations across the selected panel. The relationships are not uniform, indicating the presence of diverse factors or conditions influencing CO_2-emissions in each country.

Estimation of Panel VAR model

To address serial correlation, group-wise heteroscedasticity, and slope heterogeneity in panel data within the Panel VAR model, a robust GMM weight matrix was utilized during the estimation of model parameters. This weighting scheme enhances the reliability and accuracy of parameter estimates, ensuring the robustness of the analysis. Before applying a Panel VAR model, selecting the appropriate lag order is crucial. Upon examination of the criteria (Table 8), it is evident that MBIC, MAIC and MQIC values are notably lower at lag 2 compared to other lag orders (Paibi et al., 2022). This lower value signifies a superior trade-off between model fit and complexity. Consequently, a second-order Panel VAR model was selected as it provided a balance between capturing essential temporal dependencies in data, while avoiding excessive complexity.

The presented results from Panel VAR (Table 9) provide valuable insights into relationships between response variable and its lagged and contemporaneous values of various economic indicators, primarily focusing on the response to changes in $d(CO_2)$. The coefficient (-1) for $d(CO_2)$ enjoys a statistically significant positive relationship implying that an increase in CO_2 levels in the previous period might be associated with economic activities or factors that could positively influence the response variable. Conversely, the coefficient (-2) for $d(CO_2)$ is not statistically significant, as the influence of two-period lag is not robust. The effect of CO_2-emissions on response variable diminishes after a one-period delay, indicating a more immediate impact. Thus, CO_2-emissions can exert both short-term and long-term effects on economic activities or the response variable. The statistically significant coefficient for the one-period lag suggests an immediate impact, while the lack of significance for the two-period lag indicates a diminishing influence over time. This dynamic response underscores the complex interplay between CO_2-emissions and economic activities, influenced by the factors like policy interventions, technological changes, or market dynamics, which shape the timing and magnitude of the response (Gün, 2019; Li et al., 2022; Onofrei et al., 2022).

Considering the effects of other economic indicators, a one-unit increase in GDP from the previous period [GDP(-1)] and two periods ago [GDP(-2)] is associated with a statistically significant decrease in CO_2-emissions [$d(CO_2\ t)$], suggesting that economic growth in these periods is linked to reduced CO_2-emissions (Zhang et al. 2021; Zhilin 2021). These findings contradict the conclusions of earlier researchers (Apergis and Payne 2010; Ozcan et al. 2019). This study has also provided parallel results on examining GFCF over two-lagged periods viz., GFCF(-1) and GFCF(-2). We observed that an upswing in the GFCF during these two preceding periods was statistically associated with a notable increase in CO_2-emissions (Quanliang et al., 2023; Huijuan et al., 2021). This suggests that intensified investment during these timeframes directly contributes to elevated levels of CO_2-emissions. These results may reflect the complexity of economic relationships, as various factors can influence GDP and GFCF, affecting their impact on response variable. The coefficients of TC in one-period lag and two-period lag indicate that temperature change has a nuanced relationship with

Table 9 Determinants of CO_2-emissions using Panel VAR model (Fixed effects Model)

Response to	Response of									
	$d(CO_{2t})$		$d(GDP_t)$		$d(GFCF_t)$		$d(UPop_t)$		$d(TC_t)$	
	Coefficient	SE#	Coefficient	SE#	Coefficient	SE#	Coefficient	SE#	Coefficient	SE#
C	1.994**	0.306	2.001**	0.746	0.480**	0.172	0.021**	0.003	19.023*	8.927
$d(CO_2$ (-1))	0.651**	0.077	-0.576**	0.188	-0.039**	0.012	-0.022**	0.005	5.089*	2.526
$d(CO_2$ (-2))	0.077	0.080	-0.479*	0.225	-0.049*	0.025	-0.003	0.005	7.021*	3.329
d(GDP(-1))	-0.042**	0.015	0.657**	0.180	-0.175	0.211	0.012**	0.004	-3.739	2.159
d(GDP(-2))	-0.013**	0.004	-0.105	0.171	0.240	0.200	0.009*	0.004	-1.333	2.049
d(GFCF(-1))	0.043**	0.015	0.467**	0.158	0.934**	0.185	0.033**	0.011	2.882	2.195
d(GFCF(-2))	0.015**	0.005	0.352*	0.157	0.368*	0.172	0.011**	0.002	-1.643	1.762
d(TC(-1))	0.013**	0.003	-0.002	0.007	-0.004	0.008	0.012	0.009	-0.019**	0.004
d(TC(-2))	-0.008**	0.003	0.009	0.007	0.019**	0.008	0.009	0.040	0.037**	0.013
d(UPop(-1))	0.996**	0.211	4.541*	2.051	6.768*	3.250	1.609**	0.073	-35.328	30.319
d(UPop(-2))	0.847*	0.393	3.520	2.909	5.693*	2.761	0.630**	0.072	-28.357	34.809
R^2 Adj	0.999**		0.994**		0.993**		0.999**		0.385**	
Durbin-Watson stat	2.002		1.998		1.999		1.997		2.003	
Hausman test	85.762**		67.070**		64.238**		38.970**		45.947**	
Wald test										
F-statistic	4.489**		4.917**		4.183**		3.441**		2.274*	
Chi-square	38.913**		39.333**		33.462**		27.525**		18.193*	
Jarque-Bera Test	1.5907		1.3308		1.0249		1.0015		1.2217	

Note ** & * denote significance at 1 per cent and 5 per cent levels, respectively

- refers to Generalized Method of Moments (GMM) weight matrix: Robust. In Panel VAR model, the GMM weight matrix that is robust refers to a weighting scheme used in estimating the parameters of the model. The term "robust" in this context implies that the weight matrix is adjusted to account for potential violations of certain assumptions, such as heteroscedasticity or autocorrelation, in the data.

CO_2-emissions. While a one-period lag of temperature change led to significant increase in CO_2 emissions, a two-period lag showed a significant negative association. This may reflect the short-term effects of temperature fluctuations on energy consumption and industrial activities. For example, a sudden temperature increase might lead to increased use of air conditioning, which can contribute to higher energy consumption and CO_2-emissions. Conversely, a response to temperature changes two periods ago may involve energy-saving measures. The UPop growth strongly influences CO_2-emissions both in the short term (one-period lag) and the medium term (two-period lag). This relationship underscores the challenges posed by rising urbanization in managing emissions (Asim et al., 2020, Ribeiro et al., 2019, Salahuddin et al., 2019). In cities, there is an increasing demand for energy, transportation, and infrastructure, often leading to higher CO_2-emissions (Luqman et al., 2023). Addressing this issue requires sustainable urban planning, investments in public transportation, and adoption of clean energy sources to mitigate the carbon footprints of urbanization.

As interpretation of individual coefficients estimated in Panel VAR models can be challenging (Abrigo and Love, 2015; Lütkepohl, 2005), researchers often place higher reliance on the outcomes of Impulse Response Functions (IRFs) to elucidate and visualize the dynamic responses of the dependent variable to shocks emanating from the residual (error) terms within a panel VAR system. The IRF, in this context, assumes a central role as the focal point of our Panel VAR model analysis. Figure 3 presents the IRFs for CO_2-emissions with a 5 per cent margin of error. This graphical representation serves as a visual tool to sequentially depict the response of CO_2-emissions when subjected to one Standard Deviation (SD) shock in four key variables: GDP, GFCF, TC and UPop.

The findings indicate that GDP exhibited a consistent negative relation with CO_2-emissions over a 10-year period. This negative correlation is largely attributed to the composition of the sample, which included a majority of high-income countries, followed by upper-middle-income and lower-middle-income nations (Gross National Income (GNI) per capita). The high-income and upper-middle-income countries tend to undergo a transition from industrial and manufacturing sectors to services and technology sectors, leading to reduced emissions per unit of output. Additionally, these nations adopt stringent environmental

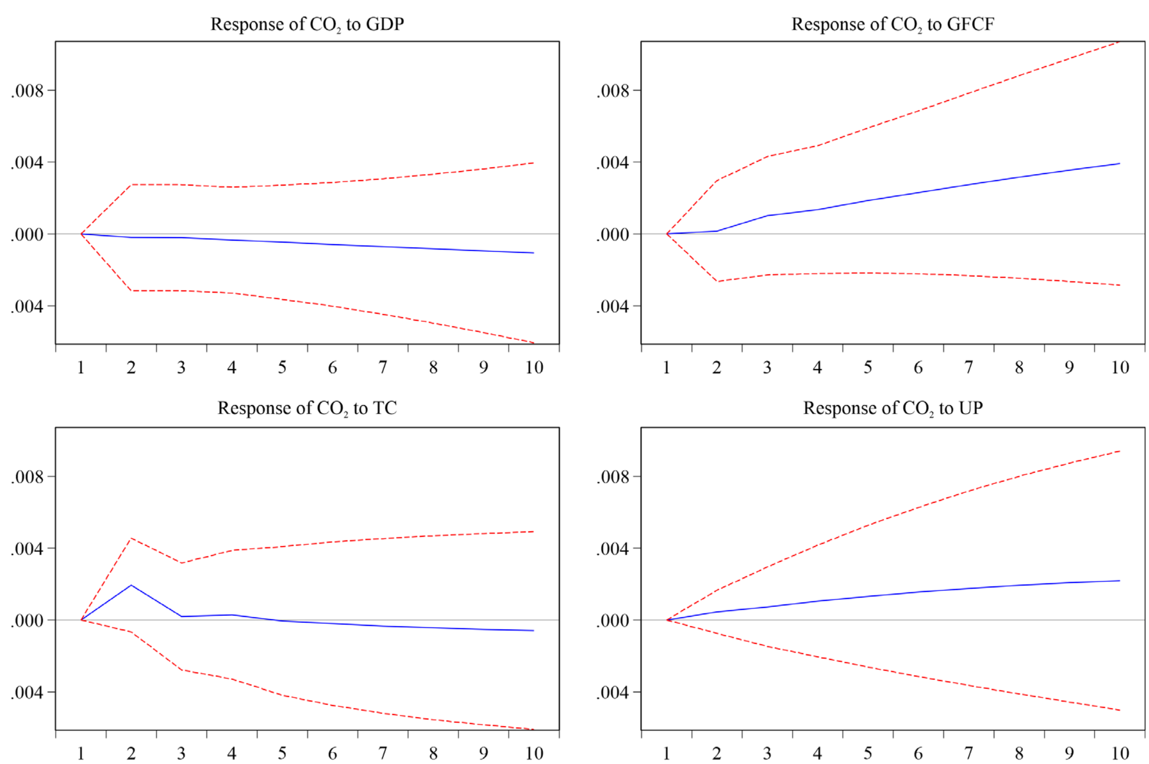

Figure 3 Reaction of CO2 to GDP, GFCF, TC and UPop for one standard deviation shock

regulations, invest in cleaner energy sources, promote sustainable consumption patterns, and encourage technological innovations, collectively contributing to emissions reduction (Elvis and Fiona, 2022; António and Rafaela, 2020; Chen et al., 2018).

Conversely, GFCF enjoys a positive relation with CO_2-emissions growth over the same 10-year period. This positive correlation is due to the nature of capital investments, which often accompany industrial growth and lead to increased production and economic activities. These activities, particularly in the energy-intensive sectors, result in elevated emissions from manufacturing, construction, and transportation. The infrastructure development, a common outcome of capital investments, also tends to be energy-intensive and contributes to CO_2-emissions. The economic development associated with rising GFCF can further amplify energy consumption and emissions if cleaner energy sources are not prioritized (Sapkota and Bastola, 2017; Gardiner and Hajek, 2020; Acheampong et al., 2021; Addo et al., 2021; Mitiæ et al., 2023).

Furthermore, the analysis delved into the impact of annual TC on CO_2-emissions growth. The results highlight a nuanced relationship characterized by an initial positive effect during the first and second years, followed by a quick decline and subsequently a weak positive correlation in short term (from the third to fifth years), ultimately transitioning into a long-term negative correlation with CO_2-emissions. This is due to delayed responses of emissions to temperature changes, short-term fluctuations, environmental policy implementations, shifts in energy sources, adaptation to climate conditions, improvements in energy efficiency, and the adoption of cleaner energy technologies (Jackson, 2017).

Lastly, the analysis emphasizes the consistent and positive relationship between urbanization (UPop) and CO_2-emissions, both in short-term and long-term. The urban areas, characterized by concentrated economic activity, increased energy demand, and extensive transportation networks, tend to generate higher emissions from industries, transportation, and energy consumption. The urbanization process often involves energy-intensive construction and infrastructure development, accompanied by changes in land use that result in emissions. Additionally, urban populations may exhibit energy-intensive consumption patterns, collectively contributing to CO_2-emissions growth (Zhang et al., 2021).

The findings of Panel VAR analysis regarding other variables, including GDP, GFCF, TC, and UPop reveal important insights. Both lagged values of d(CO_2) at -1 and -2 periods exhibit coefficients indicating a negative relationship with the respective dependent variables in the current period. However, the positive association between CO_2 and TC arises from the greenhouse effect. The elevated CO_2 levels, largely due to human activities, intensify this effect by trapping more heat in the earth's atmosphere. This excess heat contributes to global warming and subsequent climate change. Moreover, rising temperatures can trigger feedback loops, releasing additional greenhouse gases and exacerbating warming. Altered climate patterns, including extreme weather events, are further consequences of this link. Additionally, warming oceans and their acidification due to CO_2 absorption compound the environmental challenges. The negative relationship with GDP suggests that elevated CO_2-emissions may exert adverse effects on economic growth, while similar negative impacts are implied for other dependent variables. Conversely, both d(GFCF) and d(UPop) at -1 and -2 periods demonstrate coefficients suggesting positive and significant relationships with d(GDP), D(GFCF), and d(UPop) in the current period.

The high adjusted R^2 values for d(CO_2), d(GDP), d(GFCF), and d(UPop) indicate that the model could explain a substantial portion of the variance in these variables, signifying a strong fit of the model. In contrast, d(TC) did not exhibit such a strong fit. The significance of the Wald test across all response variables underscores the collective significance of a group of coefficients within the model. Specifically, the combined influence of lagged values of d(CO_2), d(GDP), d(GFCF), d(TC), and d(UPop) collectively contributes to explaining the variation observed in each response variable. As a collective unit, these variables wield a significant influence on the selected response variables within the model's framework. The results of Durbin-Watson statistic suggest that there is minimal to no autocorrelation present in the residuals, indicating that the assumption of independence among the residuals is reasonably met. Further, as the Jarque-Bera test is found non-significant across the selected models, it implies that the null hypothesis of normality in the

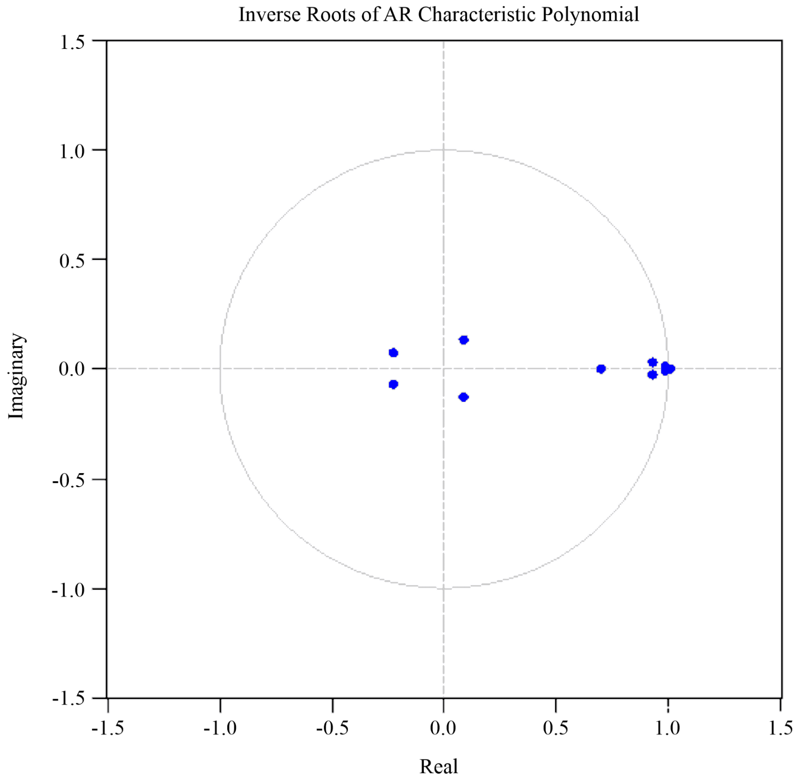

Figure 4 Stability test of Panel VAR model

distribution of the residuals cannot be rejected, indicating that the residuals follow a normal distribution.

Stability of Panel VAR model

The findings from rigorous stability test (Figure 4) revealed the reliability of our estimated model, as all covariates lie within the unit circle. This finding could provide a high degree of confidence that selected variables exhibit a stable behaviour, and their values do not diverge significantly from their historical patterns. This also implies the suitability of our model for forecasting purposes (Linus and Niraj, 2022).

Variance decomposition analysis

Table 10 present the findings looking ahead at two different time horizons: 3 years and 5 years. At a 3-year forecast horizon, the CO_2-emissions [d(CO_{2t})] would be primarily influenced by their own past values, accounting for a staggering 99.31 per cent of their own variability. This suggests that historical emission patterns strongly determine the future emissions. A similar pattern has emerged for [*D*(GDP_t)], where nearly 96.35 per cent of its variability could be explained by its own history. The [*D*($GFCF_t$)] is significantly impacted by its past values (22.92%) and past values of GDP (74.91%), highlighting the intricate relationship between investment and economic growth. Both [*D*($UPop_t$)] and [*D*(TC_t)] are predominantly shaped by their own history, 95.39 per cent and 91.08 per cent respectively.

On extending the forecast horizon to 5 years, the overall patterns remained quite consistent. The d(CO_2t) was still heavily influenced by its past values (98.98%). The d(GDP_t) continued to be predominantly shaped by its own history (91.24%). The d($GFCF_t$) maintained its reliance on both its past values (24.217%) and past values of GDP (69.573%). The d($UPop_t$) remained largely determined by its own history (94.78%). The d(TC_t) was still primarily influenced by its past (90.156%) with a minor responsiveness to GFCF (3.493%).

These findings underscore the strong autocorrelation within each economic variable, indicating past values are highly predictive of their future behaviour. Additionally, there are notable interactions between

Table 10 Variance decomposition among selected variables (%)

Period/Variable	d(CO_{2t})	d(GDP_t)	d($GFCF_t$)	d($UPop_t$)	d(TC_t)
3 Years ahead					
d(CO_{2t})	99.314	0.009	0.126	0.460	0.090
d(GDP_t)	1.596	96.349	0.019	1.762	0.274
d($GFCF_t$)	0.533	74.905	22.917	1.054	0.591
d($UPop_t$)	0.299	0.187	4.101	0.018	95.395
d(TC_t)	2.373	2.893	3.353	91.076	0.305
5 Years ahead					
d(CO_{2t})	98.967	0.029	0.459	0.283	0.261
d(GDP_t)	2.544	91.239	0.512	5.091	0.615
d($GFCF_t$)	1.212	69.573	24.217	3.504	1.494
d($UPop_t$)	0.261	0.119	4.821	0.015	94.784
d(TC_t)	2.334	3.397	3.493	90.156	0.619

Note Percentage of variation in the row variable is explained by column variable

Table 11 Panel Granger-causality test results

Response to	Response of				
	CO_2	GDP	GFCF	TC	UPop
CO_2		9.177**	5.971**	2.499	13.510**
GDP	2.601		9.361**	2.350	5.044**
GFCF	1.024	0.144		2.780	3.757**
TC	1.985	0.497	0.264		0.924
UPop	0.286	0.446	0.116	0.377	

Note ** denote significance at 1 per cent level

GDP and GFCF, a relationship of critical importance for policymakers and economists (Huanyu et al., 2022)

Panel Granger-causality

The findings from Granger-causality tests (Table 11) reveal several significant relationships. The GDP significantly Granger-causes CO_2-emissions, indicating economic growth has a substantial impact on future emissions. This finding is confirmed by the studies of Kais and Sami (2016); and Pao and Chen (2019). Similarly, the GFCF Granger-causes CO_2-emissions, suggesting that investment in fixed capital infrastructure influences the environmental outcomes. Additionally, the significant Granger-causality link between UPop and CO_2-emissions reflects urbanization's impact. The factors like concentrated economic activities, transportation demand, high energy consumption, infrastructure development, waste generation, land use changes, and distinct consumption patterns, collectively contribute to increased CO_2-emissions. However, the reverse causalities, where CO_2-emissions predict changes in GDP, GFCF, or UPop, are not statistically significant. Furthermore, relationship between TC and CO_2-emissions lacks clear statistical significance. These results underscore GDP, GFCF, and UPop in shaping the future CO_2-emissions, highlighting the potential for policy interventions targeting economic growth, investment, and employment to impact environmental sustainability.

Summary and Conclusions

The study has examined the intricate relationship between CO_2-emissions and economic development in top 20 CO_2 -emitting countries from 2011 to 2021. It casts a spotlight on various influential factors, including GDP, GFCF, TC, and UPop, with the overarching goal of unravelling their profound impact on CO_2-emissions. To decipher these complex dynamics, the study has harnessed the analytical power of Panel VAR model, allowing for a nuanced understanding of how these variables interact and influence one another.

The initial phase of study involves panel unit root tests, where data's stationarity has been assessed. It is crucial to ensure that the variables under examination exhibit stationarity before proceeding with modelling. The results have shown that after first-order differencing, all selected variables attain the requisite level of stationarity, thereby laying the foundation for the subsequent Panel VAR models. A pivotal revelation has emerged from the panel cross-section dependence test, indicating that the observations within the dataset are not independent of one another. This cross-sectional dependence implies the existence of shared common factors among the observations, a crucial consideration when analysing the data. It underscores the interrelatedness of variables across the panel. In the pursuit of understanding long-term equilibrium relationships among the variables, the panel cointegration test was conducted. Surprisingly, the findings have not strongly supported the existence of such relationships. Consequently, the analysis pivoted towards investigating the first-order differences of variables towards a more precise exploration of short-term dynamics and relationships.

With the groundwork laid, the study proceeded to the estimation of Panel VAR Model. Here, a second-order Panel VAR model was chosen as the optimal balance between capturing temporal dependencies in data and maintaining model simplicity. The findings have shown that the coefficients for lagged CO_2-emissions [d(CO_2 (-1))] exhibit significant positive relationship with CO_2-emissions during the current period. However, the coefficient for a two-period lag [d(CO_2 (-2))] is not statistically significant, implying impact of CO_2-emissions is a more immediate effect. Regarding other economic indicators, the GDP has displayed a negative influence on CO_2-emissions, implying that an increase in GDP in the previous period may lead to decrease in emissions. In contrast, the GFCF has shown a positive and significant association with CO_2-emissions. The TC has exhibited a nuanced relationship, with short-term temperature increases associated with increased emissions. The urbanization (UPop) consistently contributes to higher CO_2-emissions, highlighting the challenges posed by the urban growth in managing emissions. The IRFs have revealed that CO_2-emissions respond to one standard deviation shocks in GDP, GFCF, TC, and UPop. The analysis has also emphasized the roles of GDP and GFCF in emissions trends. The high-income and upper-middle-income countries tend to experience a transition from the industrial to service-based economies, contributing to reduced emissions per unit of economic output. In contrast, the capital investments (GFCF) often accompany industrial growth, leading to increased production, economic activity, and emissions. The analysis of temperature change (TC) has underscored the complex interplay of factors, including short-term fluctuations, energy efficiency improvements, and adoption of cleaner technologies. The urbanization has emerged as a consistent driver of emissions, necessitating sustainable urban planning and clean energy adoption to mitigate its carbon footprints. The stability test has confirmed the reliability of the estimated model, with all covariates remaining within the unit circle, instilling confidence in the model's suitability for analysis and forecasting. The variance decomposition analysis has highlighted a strong autocorrelation within economic variables, indicating that their past values strongly predict their future behaviour. The Granger-causality tests have revealed significant relationships, with GDP and GFCF Granger-causing CO_2-emissions, emphasizing the impact of economic growth and investment on emissions. The UPop Granger-causes emissions, highlighting challenges of urbanization in managing emissions. However, reverse causalities and TC-emissions relationship lack clear statistical significance.

The findings from this study have suggested that policy makers must craft strategies that strike a harmonious balance between economic growth and CO_2-emissions reduction. Prioritizing green investments to incentivize eco-friendly capital expenditure, facilitating transition to low-carbon economies through stringent regulations and sustainable practices, emphasizing sustainable urban planning to mitigate emissions from urbanization, adopting climate-resilient policies, investing in data-driven monitoring, engaging in international cooperation, implementing effective carbon pricing mechanisms, and fostering public awareness and education should all be central priorities. These multifaceted approaches aim to achieve equilibrium between economic growth and environment sustainability, effectively addressing the complexities of emissions dynamics, while underscoring the imperative for collaborative global efforts.

While this study provides valuable insights into the relationship between CO_2-emissions and various economic indicators, it is not without limitations. Firstly, the analysis has focused on a specific set of variables and might have overlooked other potentially relevant factors influencing CO_2-emissions, such as technological advancements, policy interventions, or cultural factors. Additionally, the study has relied on the panel data from top 20 CO_2-emitting countries, which may not fully capture the diversity of global emissions patterns or the unique characteristics of individual countries. Furthermore, the study's reliance on statistical models, such as the Panel VAR model, has entailed certain assumptions and limitations, including the potential for mis-specification and the sensitivity of results to model specifications. Moreover, the analysis has primarily examined short-term dynamics, and the long-term implications of the findings may require further exploration. Finally, while the study has emphasized the importance of policy interventions, it has not delved deeply into the specific policy implications or feasibility of implementing proposed strategies, leaving room for further research in this area.

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Received 23 December 2023 Accepted: 19 May 2024

Agricultural Economics Research Review 2024, 37 (1), 35-46
DOI: 10.5958/0974-0279.2024.00005.0

Unveiling the impacts of global uncertainties *ITSA Approach for quantifying the impacts of Covid-19 on agricultural trade*

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Abstract The study quantifies the impact of the Covid-19 pandemic on the bilateral agricultural trade between India and China using the Interrupted Time Series Analysis (ITSA) technique. India's agricultural exports to China increased by approximately 48 per cent post-Covid-19. The post-pandemic, cumin exports to China increased significantly due to increasing health concerns. The exports of castor oil and groundnut shot up as well. Conversely, the exports of frozen fish, shrimps, and prawns declined. However, India's agricultural imports from China, primarily fertilizers, displayed a volatile pattern. An immediate shock was observed in the case of urea and DAP imports, but the declines were not persistent for a long time.

Keywords Agricultural trade, Interrupted time series, China, Covid-19, Castor oil, Fertilizers

JEL codes Q17, Q18, F14

Introduction

Bilateral trade has played a significant role in fostering economic development and promoting economic integration globally. Since long, countries are engaged in trade with each other, enabling the smooth exchange of goods and services and co-existing harmoniously. However, in recent years various external shocks have emerged, impacting the global trade dynamics. The literature on bilateral trade has since long recognized its pivotal role in driving economic development (Panda et al., 2016). Various studies have examined bilateral trade from different perspectives, including the size of trade flows and comparative advantage (Granèay and Dudáš, 2019); trade potential (Allayarov et al., 2018); factors like market size, gross domestic product (GDP), and distance (Jan and Shah, 2019); and even the impact of information and communication technology (ICT) usage (Billon and Rodriguez-Crespo, 2020). Additionally, several studies have explored the influence of foreign direct investment (FDI) (Sohail et al., 2021); input-output trading (Nguyen et al., 2020); and the effect of free trade agreement (FTA) (Ostashko et al., 2022). The studies have also examined the trade effect of sanitary and phytosanitary (SPS) measures (Santeramo and Lamonaca, 2022) and fluctuations in exchange rates (Jan and Shah, 2019; Jiang and Liu, 2022).

The pandemic Covid 2019 worsened international trade, disrupting economic activities and macroeconomic shocks in 2020 (Khorana et al., 2022). Although necessary for public health, the initial measures led to substantial setbacks in global economic growth. The global economy contracted by about 3.2 per cent in 2020, marking one of the most significant recessions in recent history (IMF, 2021). It is evident from the extant literature that the impact of a pandemic on global agricultural trade largely depends on the type of commodity (Arita et al., 2022; Barichello, 2020; Mallory, 2021). Grains and oilseed exports were not affected much during the initial days of the pandemic (Mallory, 2021). On the contrary, beef and pork exports were significantly affected (Mallory, 2021) along with non-food items such as cotton, hides, skins, etc. (Arita et al., 2022). Further, it was found that due to some policy issues such as import restrictions, tightened sanitary and phytosanitary (SPS) measures, safety protocols, and safeguarding measures for domestic producers, etc., the trade was significantly affected during the pandemic (Barichello, 2020).

In the wake of the Covid-19 pandemic, the global landscape of bilateral trade underwent a profound transformation. The nations that were once engaged in robust trade relationships found themselves reassessing their economic ties, supply chains, and trade policies. The pandemic, which struck in late 2019, continued to disrupt economies well into 2020, posed unprecedented challenges to the world's economies. The governments worldwide implemented various measures to combat the virus's spread, including strict lockdowns, travel restrictions, and social distancing measures. Several studies have reported the adverse impacts of Covid-19 on bilateral trade across the globe during this disruption (Cardoso and Malloy, 2021; Hayakawa and Mukunoki, 2021; Li and Lin, 2021). Therefore, bilateral trade agreements, being one of the important considerations, have been revisited by several countries post-Covid to bring new regulations for e-commerce, government policies, and environmental issues (Kayani, 2021).

As countries adapted and introduced measures to mitigate the pandemic's impact, economic forecasts for 2021 and 2022 began to show signs of recovery, with projected growth rates of 6 per cent and 4.9 per cent, respectively (IMF, 2021). These forecasts represented a more optimistic outlook than the initial grim predictions for 2020. Notably, the World Trade Organization (WTO) had initially foreseen substantial declines in global trade, ranging from 8.1 per cent to 20.4 per cent under various recovery scenarios (WTO, 2020a). Nevertheless, the actual decline in total trade in 2020 was smaller than anticipated at -5.3 per cent, attributed to factors such as strong monetary and fiscal policies, innovative business and household adaptations, and trade policy restraints (WTO, 2021).

Surprisingly, agricultural trade displayed remarkable resilience during the pandemic, surpassing initial projections. The agricultural trade expanded by 3.5 per cent in 2020, driven by factors that included the industry's essential nature, low-income elasticity of food demand, and the fact that shipping channels required a minimal human interaction (WTO, 2020b). However, this resilience coexisted with global food insecurity, as an estimated 768 million people faced hunger in 2020, representing an increase of 118 million compared to the previous year (FAO, 2021).

The Covid-19 crisis prompted a comprehensive re-evaluation of traditional trade practices, with governments and businesses worldwide grappling with the need for adaptability and resilience in the face of unexpected challenges. The studies have also examined the impacts of Covid-19 on international trade. Early analyses indicate temporary disruptions in beef and pork markets, but not in grains and oilseeds markets (Mallory, 2021). China, a significant player in the export of agricultural goods, also experienced a substantial decline during the initial wave of Covid-19, primarily attributed to internal supply disruptions and decreased global import demand (Friedt and Zhang, 2020).

Against this backdrop, the bilateral trade relationship between China and India, two of Asia's most populous and fastest-growing economies, assumed great significance. China has long been India's primary trading partner, thanks to the substantial growth of bilateral trade between the two nations since early-2000s. During 2015 to 2022, the bilateral trade between the two countries increased by 90.14 per cent, with an annual growth of 12.87 per cent (Chinese Embassy in India, 2023). However, the impact of Covid-19 on bilateral agricultural trade between India and China has remained largely unexplored. As both the countries are key players in the global agricultural market, the consequences of the pandemic on their agricultural trade dynamics are of critical importance. Considering this, a comprehensive study was undertaken with two primary objectives: (i) examining the evolving trends in bilateral agricultural trade between India and China, and (ii) quantifying the impact of the Covid-19 pandemic on India's agricultural trade with China.

Data and methodology

The study is rooted in monthly time series data from January 2017 to December 2021, focusing on the HS-6 classification of commodities retrieved from the INTRACEN (International Trade Centre) database. Accordingly, the seven top agricultural commodities traded between India and China were selected for the study (Box 1). These commodities included frozen fish, shrimps and prawns, chili, cumin, castor oil, groundnut oil, and cotton yarn. Along with these commodities, fertilizers such as Urea and DAP were also selected for the study. For cumin and groundnut oil, monthly data from March 2019 to December 2021 were considered due to unavailability of continuous data series. International Time Series Analysis (ITSA) was carried out to estimate the impact of Covid-19 on the bilateral agricultural trade between India and China.

Interrupted time-series analysis (ITSA)

Panda et al. (2016) investigated the bilateral trade flows between China and India in two phases: pre- and post-economic crises of 2008-09. They revealed that geographical proximity played a substantial role in driving trade flows between countries. It was observed that while examining bilateral trade, researchers have frequently applied the gravity model approach to test their underlying hypotheses (Allayarov *et al.*, 2018; Balogh and Borges Aguiar, 2022; Cieœlik and Gurshev, 2022; Granèay and Dudáš, 2019; Guðjonsson *et al*., 2021; Jan and Shah, 2019; Santeramo and Lamonaca, 2022). However, the Interrupted time series analysis (ITSA) is found most plausible approach in the extant literature to examine the interruptions due to unforeseen events such as economic crises, war, and pandemics (Anderton and Carter, 2001; Crookes et al., 2020; Laliotis et al., 2016; Lopez Bernal et al., 2013). Hence, this study attempts to investigate the behaviour of bilateral trade between India and China amid the unforeseen events of Covid-19 through the lens of ITSA to provide valuable insights into the impact of this crisis on their trade dynamics.

The ITSA has been widely used in assessing the effects of public policy change (Muller, 2004), regulatory actions (Briesacher et al., 2013), and large-scale community interventions (Biglan et al., 2000; Gillings et al., 1981). The ITSA is preferred over other methods because it requires only one treatment unit. It is optional to have a control group for comparison (most suitable in situations where identifying a control group is difficult). It has strong internal validity and provides outcome results graphically to supplement the statistical results (Linden, 2015). In the present study, we have used ITSA, a quasi-experimental research design, to quantify the effect of Covid-19-induced lockdown policy on the export of major agricultural commodities from India to China and the import of fertilizers from China to India (Cariappa et al., 2022; Bernal et al., 2017). The Covid-19 shock is assumed to be entirely exogenous. India witnessed the spread of Covid-19 in March 2020, when the government took

Box 1 Details of agricultural commodities selected for study

HS code	Product description	Short name
030389	Frozen fish, n.e.s.	Frozen Fish
030617	Frozen shrimps and prawns, even smoked, whether in shell or not	Shrimps and Prawn
090421	Fruits of the genus Capsicum or of the genus Pimenta, dried	Chilli
090931	Cumin seeds, neither crushed nor ground	Cumin
151530	Castor oil and fractions thereof, whether or not refined, but not chemically modified	Castor oil
150810	Crude groundnut oil	Groundnut oil
520512, 520514, 520522, 520523, 520524	Single cotton yarn, of combed and uncombed fibres (Combined)	Cotton yarn
310210	Urea, whether or not in aqueous solution	Urea
310530	Diammonium hydrogenorthophosphate “diammonium phosphate”	DAP

Source: INTRACEN database

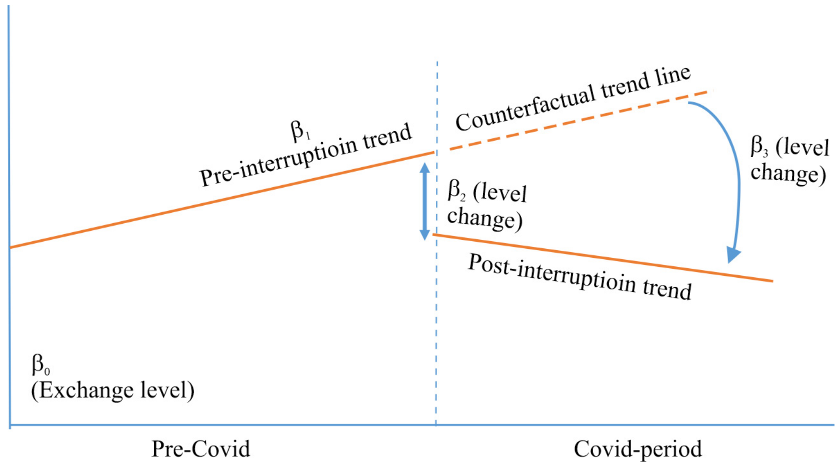


Figure 1 ITSA with policy intervention

several measures to contain the pandemic. Hence, March 2020 was selected as a breakpoint in the ITS analysis. The study has considered two periods: January 2017 to February 2020, the pre-intervention (pre-Covid) period, and March 2020 to December 2021, the post-intervention period (Covid period). The function form used in the study for the Covid-19 shock is depicted in Figure 1 and explained in Equation (1).

$$Y_{it} = \beta_0 + \beta_1\, time_t + \beta_2 \mathrm{COV}level_i + \beta_3\, \text{Post-COV}trend_{it} + \varepsilon_{it} \quad (1)$$

where, Y_{it} represents the exports or imports in value-terms, the outcome variable; β_0 is the level at t=0, β_1 is the pre-intervention trend (i.e., before Covid-19), β_2 is the post-intervention level change that captures the impact of the Covid-19 shock, and β_3 is the post-intervention slope change. The β_2 and β_3 coefficients indicate the immediate and over-time Covid-19 effects, respectively (Figure 1). The ITSA is based on the ordinary least square regression approach and provides Newey-West standard errors, which account for autocorrelation and possible heteroscedasticity problems. We have also used another STATA "actest" package (Baum and Schaffer, 2013) to decide the number of lags to be included in the ITSA model, having a default Cumby–Huizinga general test for autocorrelation (Cumby and Huizinga, 1992).

Results and discussion

Trends in bilateral trade between India and China

While the overall trade between India and China has grown significantly, the trajectory of India's agricultural exports to China is marked by fluctuations. These variations reflect the bilateral trade relations' dynamic and evolving nature, influenced by multiple economic, political, and strategic factors. Understanding these trends is crucial for the stakeholders aiming to enhance and stabilize India's agricultural export performance in the Chinese market. In 2021-22, China emerged as India's second-largest trading partner, just after the United States. Since the beginning of the 21st century, the trade relationships between India and China have experienced significant growth. From 2015 to 2022, the bilateral trade between the two countries surged by an impressive 90.14 per cent, translating to an annual growth rate of 12.87 per cent, ultimately reaching a substantial USD 136.26 billion in 2022.

Despite the robust overall trade growth, India's total merchandise exports to China have shown an inconsistent pattern, a phenomenon particularly pronounced in the agricultural exports. Initially, India's share of agricultural exports to China sharply declined, plummeting from 22.51 per cent in 2000-01 to just 10.09 per cent in 2009-10. However, in a surprising turnaround, the share of agricultural exports to China experienced a significant resurgence, soaring to 37.06 per cent in 2013-14. Nevertheless, the subsequent years saw a stabilization of this share, with the recent three-year span from 2019-20 to 2021-22 maintaining an average of approximately 20 per cent (Figure 2). This stabilization indicates a more balanced and consistent trade pattern, albeit at a lower level than the peak observed in 2013-14.

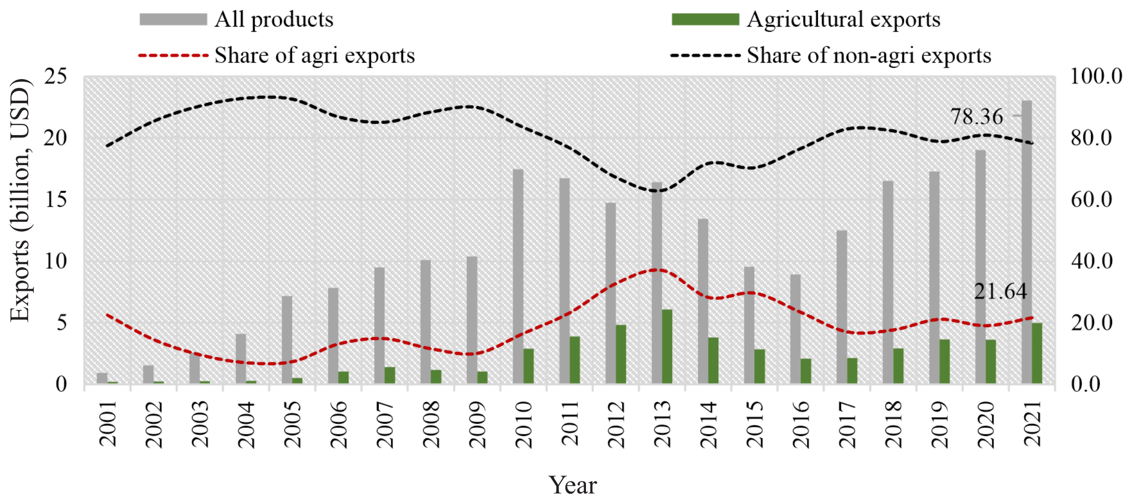


Figure 2 India's exports to China
Source INTRACEN database

Notably, the expansion in trade with China can be attributed predominantly to a notable upswing in imports, as China emerges as India's foremost import trade partner in the fiscal year 2022. During the past two decades, India has been procuring substantial quantities of non-agricultural goods from China, steadily increasing its share. However, the share of agricultural imports from China has diminished over the years (Figure 3). Since 2001-02, the share of agricultural imports has declined from 4.10 per cent to 0.57 per cent by 2021-22.

Beyond agricultural commodities, India has been importing substantial quantities of farm inputs, notably fertilizers, from China (Figure 4). Before 2006-07, India's fertilizer imports from China were relatively minimal, indicating a limited reliance on Chinese supplies for these crucial agricultural inputs. However, this scenario began to change dramatically from 2007-08 onwards. The data reveals a striking escalation in fertilizer imports from China, which surged from USD 872 million in 2007-08 to an impressive USD 2687 million by 2021-22, indicating an enhanced dependency on Chinese fertilizers to meet its input demand.

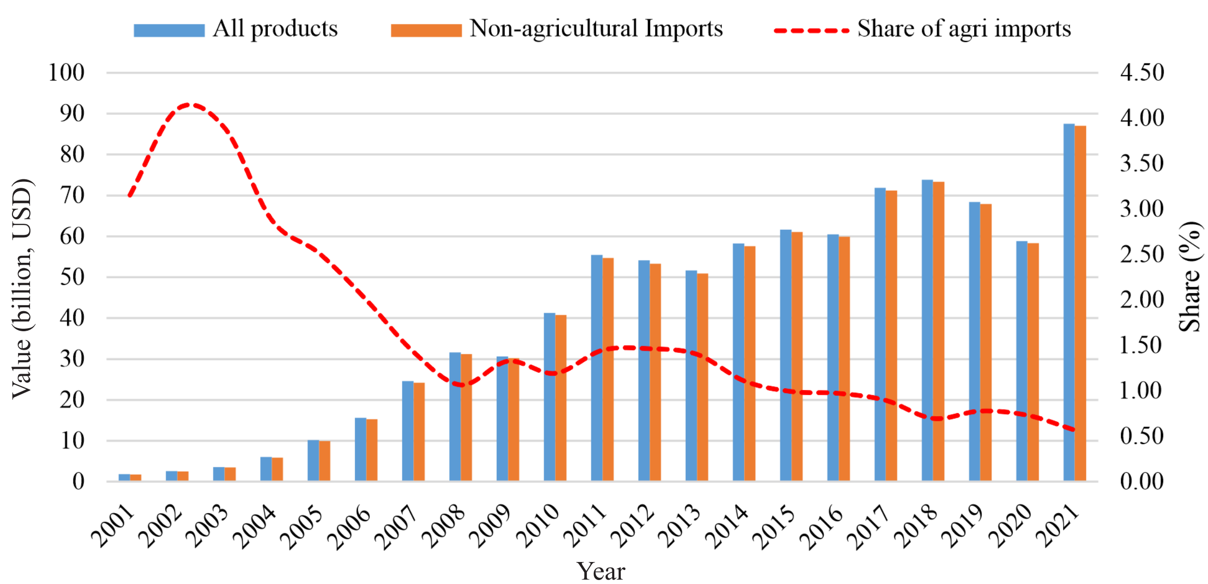


Figure 3 Share of agricultural and non-agricultural imports from China
Source INTRACEN database

Figure 4 Fertilizer imports from China (Million, USD)
Source INTRACEN database

Covid-19 and bilateral agricultural trade

India's primary trade partners include the United States, China, the United Arab Emirates, and Saudi Arabia. Among these, China stands as a significant partner. China's role in India's trade ecosystem is substantial. It accounts for approximately 11 per cent of India's total trade, making it one of India's largest trading partners. The trade relationship is marked by a significant imbalance, with India importing more goods from China than its exports to the Chinese market. Specifically, around 15 per cent of India's total imports, including many products, originate from China. On the export front, India exports about 6 per cent of its overall exports to China. The Covid-19 pandemic introduced unprecedented challenges to global trade, and the Indo-China trade corridor has not been immune to these disruptions. The lockdowns, logistical challenges, and changing trade policies during the pandemic affected these two nations' import and export activities. The trade data before and during the pandemic, presented in Table 1 and Table 2, provide a comprehensive view of these dynamics and form the basis for analyzing the

Table 1 Covid-19 and bilateral agricultural exports to China

Particulars	Exports (million, USD)		
	Pre-Covid(TE 2019)	Post-Covid(BE 2021)	Change, %
All products	15428.68	21022.43	36.26
Total agricultural exports	2903.79	4306.93	48.32
Fish and crustaceans, molluscs	700.46	961.78	37.34
Edible vegetables	11.14	47.39	325.23
Edible fruit and nuts	7.64	9.98	28.43
Coffee, tea, and spices	191.79	635.71	231.46
Cereals	0.25	190.01	76932.50
Oil seeds and oleaginous fruits	31.85	96.26	202.19
Animal or vegetable fats and oils	408.98	698.11	70.70
Sugars and sugar confectionery	12.10	55.87	361.55
Cotton	1222.05	1360.95	11.37
Other agri exports	317.52	257.48	-21.02
Share of agri exports (per cent)	18.65	20.36	
Share of non-agri exports (per cent)	81.35	79.64	

Source INTRACEN database

Table 2 Covid-19 and bilateral agricultural imports from China

Particulars	Imports (million, USD)		
	Pre-Covid (TE 2019)	Post-Covid (BE 2021)	Change, %
All products	71379.41	73166.98	2.50
Total agricultural imports	562.86	462.84	-17.77
Cotton	125.31	79.97	-36.18
Other vegetable textile fibres	102.96	65.67	-36.21
Edible vegetables	59.01	42.11	-28.64
Edible fruit and nuts	48.56	11.83	-75.65
Wool, fine or coarse animal hair	41.28	29.19	-29.29
Vegetable planting materials	33.51	63.16	88.49
Raw hides and skins	32.60	25.32	-22.34
Preparations of vegetables, fruit	25.20	24.82	-1.51
Lac, gums, resins	20.49	27.77	35.53
Other agriculture items	73.94	93.00	25.78
Share of non-agri imports (per cent)	99.21	99.35	
Share of agri imports (per cent)	0.79	0.65	

Source INTRACEN database

repercussions of the pandemic on Indo-China trade.

Following the onset of the Covid-19 pandemic, India has witnessed a significant increase in its exports. This upward trend is particularly evident in India's agricultural exports to China, which saw a remarkable surge post-pandemic (Table 1). Interestingly, cotton consistently emerged as the most exported commodity during both time frames, followed by fish and crustaceans. However, the most notable growth in agricultural exports was observed in cereals. This category experienced an extraordinary increase, reflecting the growing demand in the Chinese market. Sugar also witnessed a considerable growth, reflecting the diversification of India's agricultural export portfolio. Additionally, edible vegetables, coffee, tea, and spices recorded significant export gains. This surge in agricultural exports can be attributed to several factors. First, the disruption in global supply chains caused by the pandemic prompted China to diversify its import sources to ensure food security. Second, the strong bilateral agreements and trade policies between India and China facilitated smoother trade flows, despite the pandemic-induced challenges.

While there was a marginal increase in India's imports from China post-Covid-19 pandemic, a contrasting pattern emerged for agricultural imports, which experienced a decline after the onset of Covid-19. Among majorly imported agricultural commodities, edible fruits and nuts showed the highest decline, followed by cotton and other vegetable textile fibres. However, during this period, there was a rise in imports of commodities such as vegetable planting materials, lac, gums, resins, etc.

The Pandemic impacts on trade

The disruptions caused by the Covid-19 measures had notable effects on global supply chains, particularly in the agricultural trade. Enhanced food safety protocols were enforced, thereby influencing trade dynamics. In the context of India-China agricultural trade relations following the onset of the pandemic, the study employed Interrupted Time Series Analysis (ITSA) to evaluate the impact comprehensively. The outcomes of the ITSA, as depicted in Figure 5 and detailed in Table 3, shed light on the repercussions of Covid-19 on the agricultural trade between India and China. The fisheries products faced many stringent import requirements from the importing countries, particularly during the initial phase of the pandemic, when apprehensions existed about animal-to-human transmission of the virus (Saxena et al., 2022). As a

Table 3 ITSA estimates of effect of Covid-19 on India's agricultural trade with China

Commodities	Pre-Covid		Post-Covid		F-stat	Sig F-stat
	β_0 Intercept	β_1 Pre-trend	β_2 Cov-level	β_3 Post-covid trend		
Export						
Frozen fish	-2555.45	936.86***	-17948.5*	-1033.12**	5.87***	0.0015
Shrimps and prawns	-11628.70	2507.38***	-33822.6	-1800.27**	17.92***	0.0000
Chillies	-4980.05	863.92***	5611.90	-577.00*	42.44***	0.0000
Cumin	15761.33***	-1081.46*	16905.48***	417.83	4.56***	0.0095
Castor oil	35032.34***	-198.26	4323.78	790.22**	2.65**	0.0574
Groundnut oil	-922.37	653.10***	18207.94	-1170.14	5.25**	0.0049
Cotton yarn	87216.95***	-711.60	-23462.00	3021.36**	3.48**	0.0218
Import						
Urea	-8867.87	2752.51**	-76598.00	5013.64	7.19***	0.0004
DAP	68768.62***	478.47	-56617.40	3458.30*	2.35*	0.0825

Note ***, **, and* represent level of significance at 1, 5 and 10 per cent, respectively

result, exports of frozen fish, shrimps, and prawns declined significantly after the onset of Covid-19.

Cotton is a dominant export commodity. India is amongst the largest cotton producers and exporters of cotton yarn. China is the biggest buyer of India's cotton. Like other products, cotton yarn exports dipped to the lowest levels during the decade due to the Covid-19 pandemic across the globe. A similar decline was noticed in India, too. However, the country improved its global trade share and increased cotton exports tremendously in 2021, much higher than in the pre-Covid period. The same has been observed through the negative β_2 coefficient and significantly positive trend coefficient.

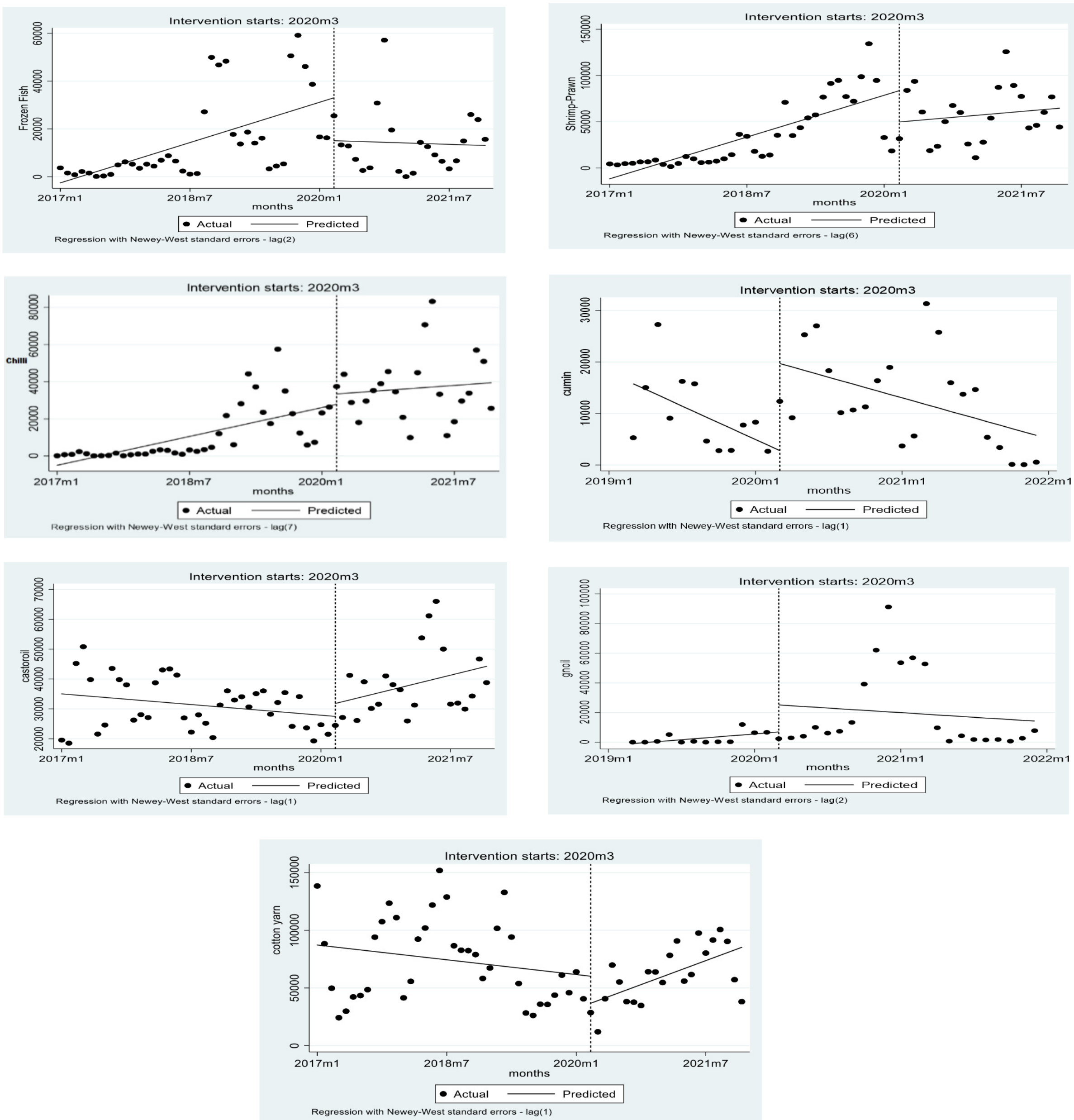
The occurrence of the Covid-19 pandemic worldwide created a lot of health concerns and reliance on herb-based ayurvedic medicines. This led to a global upsurge in the demand for spices. India is the world's largest producer, consumer, and exporter of spices and their value-added products. Spices like chili, cumin, etc., have known therapeutic qualities, and their exports have increased substantially (Saxena et al., 2022). China is India's largest importer of these products, followed by Bangladesh. There was a surge in the demand for chili and cumin, which impacted India's overall exports. The same has been observed through positive coefficients.

China has aggressively bought castor and groundnut oils from India to bolster its state reserves. After Covid-19, despite a decline in overall castor oil exports from India, imports from China still increased, as observed through the positive and significant coefficients (β_2 and β_3). In contrast, groundnut oil exports suddenly picked up because of a sudden rise in demand from China. However, their exports declined thereafter.

In India-China agricultural trade dynamics, India's agricultural imports share is less than one per cent of the bilateral trade between them. And even after the pandemic, the share has remained almost constant, i.e. below one per cent. Besides agricultural commodities, India imports huge amounts of farm inputs, particularly fertilizers, from China. The study further delves into this facet by examining the impact of Covid-19 on imports of urea and DAP (Di-ammonium phosphate) from China. Interestingly, the immediate shock was observed in the case of urea and DAP imports through negative but insignificant coefficients. However, these declines were not persistent for a longer time, as a positive trend was observed thereafter, indicating an upward trajectory of imports of these fertilizers.

In nut-shell, the performance of India's bilateral agri-exports to China during the Covid-19 pandemic is a testament to the effectiveness of its export-enhancing measures. These measures include the short-term elimination of export duties, removal of export

Exports



Imports

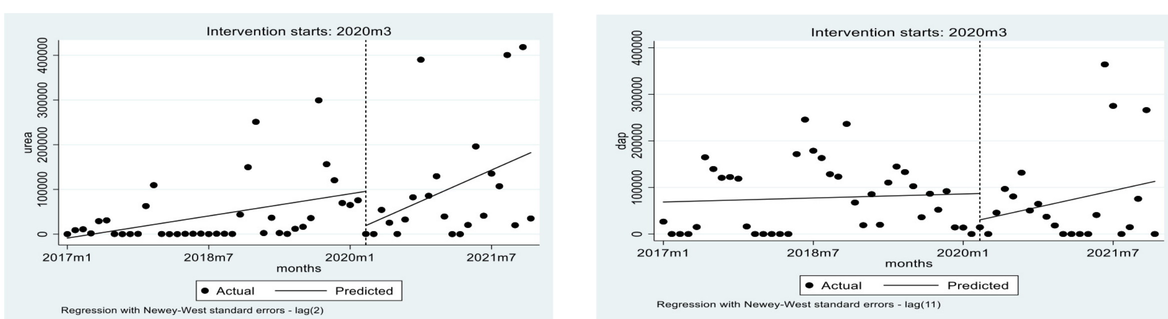


Figure 5 Effect of Covid-19 on India's agricultural trade with China

prohibitions, terminating prior export authorization, etc. The same has been indicated through the findings of the study as it underscores the complex interplay between the disruptive impacts of the pandemic, evolving trade policies, and the economic realities of India-China agricultural trade dynamics.

Conclusions

The pandemic Covid-19 exacerbated many challenges, highlighting vulnerabilities in the global trade system. The study comprehensively explains how the Covid-19 pandemic reshaped the agricultural trade landscape between India and China. The analysis of export trends, particularly the remarkable increase in certain commodities and the decline in others offers valuable insights for policymakers and businesses looking to navigate the post-pandemic trade environment.

The study reveals a significant increase in India's agricultural exports to China, surging by nearly 48 per cent following the pandemic. This increase highlights the dynamic shifts in trade patterns amid global disruptions. One of the most notable findings is the substantial rise in cumin exports from India to China immediately after the pandemic onset. This surge highlighted growing demand in the Chinese market. Alongside cumin, other commodities such as chillies, castor oil, and groundnut oil also experienced post-pandemic growth, albeit without a statistically significant coefficient. Conversely, the study reports a significant decline in the export of frozen fish from India to China immediately after the pandemic onset. This can be attributed to many factors, such as supply chain disruptions, logistical challenges, and perhaps shifts in market demand due to the pandemic.

India's agricultural imports from China, primarily consisting of essential farm inputs like fertilizers, exhibited a volatile pattern during the Covid-19 pandemic. Initially, there was an immediate decline in the imports of urea and diammonium phosphate (DAP) following the onset of the pandemic. However, the post-pandemic period showed a noteworthy shift in this trend. While urea imports faced challenges, the import trend for DAP began to signal an upward trajectory. This increase in DAP imports indicated a recovery and possibly an increased demand for this crucial fertilizer as agricultural activities resumed and intensified post-pandemic.

The examination highlights the complex interplay of the pandemic's disruptions, trade policies, and economic conditions. As India seeks to boost its exports, it grapples with difficulties posed by partner nations' restrictive trade policies. The expansion of two-way exports is shaped by many elements, encompassing limitations within both exporting and importing countries, such as infrastructure challenges and ineffective institutions, trade-related measures such as tariffs and currency exchange rates, etc. This emphasizes the need to swiftly implement strategic actions to navigate these intricacies and cultivate robust trade partnerships.

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Received 10 February 2024 Accepted 21 June 2024

Agricultural Economics Research Review 2024, 37 (1), 47-58
DOI: 10.5958/0974-0279.2024.00006.7

Impact of climate change on agriculture in Indo-Gangetic Plains of India

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Abstract The agriculture sector is highly vulnerable and sensitive to climatic variations. This study estimates the impact of climate change on the yields of both rabi and kharif crops in the Indo-Gangetic Plains of India. The projected impact on the crop yields under RCP 4.5 climatic scenario has revealed that by 2050 and 2080, the yields of paddy would decline by 24.23 per cent and 30.48 per cent; of maize by 10.09 per cent and 12.51 per cent; of pearl millet by 0.5 per cent and 1.43 per cent; of wheat by 6.06 per cent and 7.43 per cent; of sugarcane by 2.35 per cent and 2.96 per cent, respectively. On the other hand, the yields of chickpea, rapeseed & mustard and cotton would show an increase by 5.55 per cent and 6.52 per cent; 0.75 per cent and 1.31 per cent; and 3.69 per cent and 5.44 per cent, respectively by 2050 and 2080. The study has recommended the development of appropriate adaptation strategies including suitable crop mix to mitigate the negative impact of climate change as well as would ensure food security for the increasing population of India.

Keywords Climate change, crop yields, Indo-Gangetic Plains, yield projection, 2040, 2050, 2080

JEL codes Q1, Q51, Q54

Introduction

Climate change has become one of the most serious issues in the world. The extent of literature on the impact of climate change shows its notable effects on all sectors of the economy (Dubey and Sharma, 2018). The agriculture sector, particularly in developing countries is more vulnerable and sensitive due to climatic changes because more than 50 per cent rural population is engaged in agriculture and allied activities for their subsistence. The developing nations have fewer physical and economic resources to thwart the negative effects of climate change on agriculture as compared to the developed nations. (Kumar et al., 2015; Jyoti, and Singh, 2020; Singh, 2021). Moreover, these nations are located at low latitudes, due to which agricultural production is extremely vulnerable to climate change (Lee, 2009; Ahmad et al., 2011; Jyoti, and Singh, 2020). In India, several studies have estimated the impact of climate change on agricultural output and food security, based on the projection of crop yields (Agarwal and Mall, 2002; Pathak et al., 2003; Byjesh et al., 2010; Birthal et al., 2014; Saravanakumar, 2015 Abeysingha et al., 2016; Singh et al., 2019a; Singh et al., 2020). The broad analysis indicates large variations in the predictions made on the impact of climate change on crop yield.

In this study, we focus on the Indo-Gangetic Plains (IGP), covering the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. These states are situated in the north of India, have the world's most intensely farmed area and cover nearly 20 per cent of the total geographical area of India. The IGP is also considered to be India's bread basket for ensuring food security of the nation (Agarwal et al., 2000). These states have immense groundwater potential and a well-developed canal irrigation system. The historical trends in the IGP have shown large variations in rainfall and a rise in mean temperature (Khatri-Chetri et al., 2016). However, yield gaps in paddy/rice and wheat exist in most of the region. To meet the growing demand for food, it is necessary to understand and take measures to increase the yield potential of the crops in the IGP region. It is maintained that more emphasis should be given on the development of Bihar and Uttar Pradesh in this region to sustain the food security of the country as these states have untapped potential for wheat and rice (Agarwal et al., 2000). Only a few studies have been done in this region to estimate the effects of climate change on yield. The present study has been undertaken to estimate the changes in climatic factors over time, their marginal effects, and their impact on agricultural productivity in India's IGP in the future. The analysis is based on select crops grown in the IGP, and be helpful in drawing the attention of the policymakers towards effective crop-specific policies that may combat the impact of climate change on agriculture.

Data and methodology

A panel data approach was used to establish the relationship between crop yield and weather variables. For this, a comprehensive district-level panel was constructed from 1966-2020, covering 90 districts spread across five states in the Indo-Gangetic plains as per their 1970 boundaries. The crops subjected to the empirical analysis included four kharif crops (rice, maize, cotton, pearl millet) and four rabi crops (wheat, chickpea, rapeseed & mustard, and sugarcane). The selection of crops was based on their corresponding area of dominance in each state of the region. The data on crop area (ha) and production (tonnes) and non-climatic factor- net irrigated area (ha) was compiled from the database maintained by the International Crops Research Institute for the Semi-Arid Tropics (http://data.icrisat.org/dld/) and Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Govt. of India, New Delhi (https://eands.dacnet.nic.in/). The data on rainfall and temperature for the districts were extracted from daily gridded data obtained from the India Meteorological Department, Government of India, New Delhi. The daily temperature, minimum, and maximum, were later transformed into the average crop-growing period temperature, and the daily rainfall was summed up to represent the cumulative rainfall during the crop-growing period. The fixed effect panel model to examine the impact of climate change is specified as Equation (1):

$$\ln y_{it} = D_i + T_t + \beta X_{it} + \gamma Z_{it} + \varepsilon_{it} \qquad \ldots(1)$$

where, subscripts i represent district and t represent time. The dependent variable y is the crop yield and D represents the district's fixed effects.

It was hypothesized that district fixed effects absorb all the unobserved district-specific time-invariant variables (soil characteristics, elevation, water quality) that influence crop yields, and also reduce error due to excluded variables in the model. The time-fixed effects are represented by T in the model that controls the variation in the crop yield, which might originate due to changes in infrastructure, technological factors, human capital, etc. The X represents a vector of weather variables - temperature and rainfall, and Z accounts for the vector of non-weather variables- net irrigated area under a particular crop, β, and γ are parameters associated with explanatory variables; and ε is the random error term. Equation (1) was estimated as semi-log linear to reduce excessive variation in the dependent variable which was crop yield (kg/ha). In this model, irrigation was taken as an exogenous variable.

Test of stationarity in data

It is essential to check whether the variables are stationary before performing any statistical analysis. The stationarity of dependent and independent variables was checked using the Levin–Lin–Chu; Im, Pesaran and Shin; and the Fisher-type tests and results (Choi, 2001; Levin et al., 2002; Im et al., 2003). Table 1 presents the results obtained from these tests.

Based on the results, the null hypothesis of all panels being unit roots was rejected at 1 per cent significance level, indicating that the variables in the models were stationary.

Results and discussion

Trends in climate variables in the IGP of India

Understanding the trends in rainfall and temperature is essential before discussing the impact of various

Table 1 Stationarity tests for variables used in the regression analysis

Variable	Levin-Lin-Chu unit root test			Im-Pesaran-Shin unit root test		Fisher-Type unit root test	
	H_0: Panels contain unit roots			H_0: Panels contain unit roots		H_0: Panels contain unit roots	
	H_a: Panels are stationary			H_a: Panels are stationary		H_a: Panels are stationary	
	Unadjusted t	Adjusted t	p-value	z-t-tiled bar	p-value	Chi-sq (pm)	p-value
Max. Temp. (*Kharif*)	-48.153	-31.152	0.000	-39.389	0.000	215.51	0.000
Max. Temp. *(Rabi)*	-45.920	-26.245	0.000	-30.755	0.000	128.97	0.000
Min. Temp. *(Kharif)*	-29.503	-15.746	0.000	-30.353	0.000	91.73	0.000
Min. Temp. *(Rabi)*	-30.455	-18.977	0.000	-29.049	0.000	56.77	0.000
Average Temp. *(Kharif)*	-39.175	-23.705	0.000	-36.684	0.000	164.59	0.000
Average Temp. *(Rabi)*	-42.948	-25.279	0.000	-30.493	0.000	117.42	0.000
Rainfall (*Average)*	-44.401	-28.411	0.000	-38.598	0.000	204.46	0.000
Rainfall *(Kharif)*	-44.767	-29.221	0.000	-38.791	0.000	198.07	0.000
Rainfall (*Rabi)*	-48.251	-33.848	0.000	-40.718	0.000	183.86	0.000
ln (Paddy yield)	—	—	—	-28.972	0.000	20.50	0.000
ln (Wheat yield)	—	—	—	-29.323	0.000	21.01	0.000
ln (Maize yield)	—	—	—	—	—	26.92	0.000
ln (Sugarcane yield)	—	—	—	-29.375	0.000	34.17	0.000
ln (Cotton yield)	—	—	—	—	—	9.97	0.000
ln (Pearl millet yield)	—	—	—	—	—	44.03	0.000
ln (Chickpea yield)	—	—	—	-25.233	0.000	75.70	0.000
ln (Rapeseed & mustard yield)	—	—	—	-28.598	0.000	26.60	0.000
ln (Sesamum yield)	—	—	—	-19.514	0.000	47.48	0.000

Note Levin-Lin-Chu and Im-Pesaran-Shin test requires balance panel data.

factors on crop yields. The Mann–Kendall test was used to test the significance of trends in rainfall and temperature for the rabi and kharif seasons. The magnitude of trend was calculated using Sen's slope estimator. Table 2 Presents the results.

It can be observed that minimum and average temperatures have increased significantly while rainfall and maximum temperatures have shown a declining trend over time in the IGP during the rabi season. The maximum temperature shows a non-significant declining trend during the rabi season and an increasing trend during the kharif season. A significant increasing trend can be observed in the average, and maximum temperatures, while rainfall declined significantly during the kharif period. The increase in the annual average temperature during the kharif season was more than that during the rabi season.

To understand the behaviour of climate variables, daily mean, maximum and minimum temperatures and cumulative rainfall for the growing season were plotted for the period 1966-2020 in Figures 1, 2 and 3, respectively. A look at Figures 1 and 2 reveals a clear rise in temperature in both kharif and rabi seasons; the trend being somewhat stronger in the rabi season. However, it is the minimum temperature in the rabi season and the maximum temperature in the kharif season that have driven the change in mean temperature. A perusal of Figure 3 does not reveal any significant trend in rainfall during the rabi season. On the other hand, there is a negative trend in the kharif rainfall during the period 1966- 2020. These long-term changes in weather variables suggest that the impacts of climate change in India are largely driven by the rise in temperature and not much by the change in rainfall.

Impact of climate change on crops yield

The changes in climatic variables will affect different crops in different ways. The production of various crops

Table 2 Trends in temperature and rainfall:1966-2020

Season→	*Rabi*			*Kharif*		
Particulars	MK statistic	Z-statistic	Sen's Slope estimator	MK statistic	Z-Statistic	Sen's Slope estimator
Mean temp.	277	2.00***	0.009	409	2.96***	0.012
Max. temp.	-103	-0.74	-0.003	219	1.58	0.009
Min. temp.	715	5.18***	0.021	721	5.23***	0.015
Rainfall	-105	-0.75	-0.235	-331	-2.40***	-2.283

Note *** indicates significance at 1per cent, level of significance

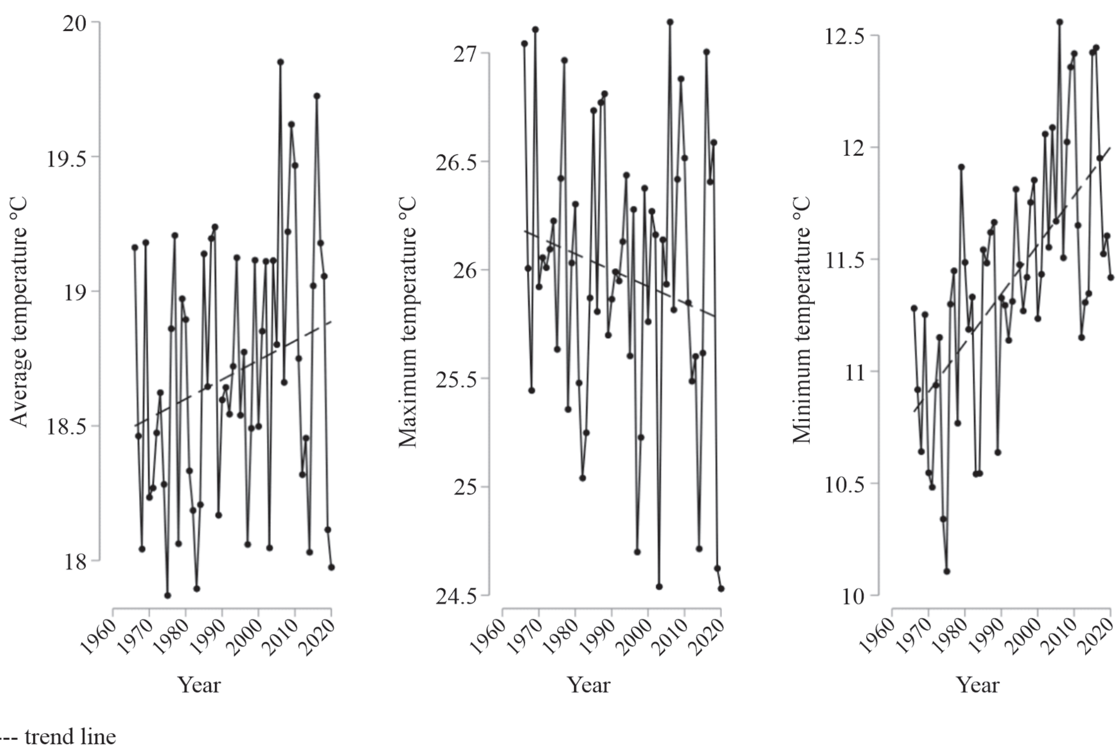


Figure 1 Trend in average, maximum and minimum temperature during *rabi* season in IGP: 1966-2020

has increased since the use of high-yielding variety seeds, pesticides, fertilizers, irrigation and mechanization (Aryal et al., 2018). However, sustaining the benefits of Technology adoption is becoming more difficult due to negative environmental externalities (Pingali, 2012), mainly the depletion of groundwater, which is the major source of irrigation. In this aspect, the discussion in the study includes the marginal effects and the future projections of the impact of climate change on crop yields.

Regression results

The climate variables along with the square of climatic variables and their interaction with the net irrigated area and time (year) were regressed with the log of crop yield after controlling for the district-fixed effects. Table 3 presents the results for kharif crops and Table 4 shows the results for the rabi crops. A perusal of Tables 3 and 4 reveals that the district-fixed effects are significant in all the crops irrespective of growing seasons, suggesting that it is important to control the

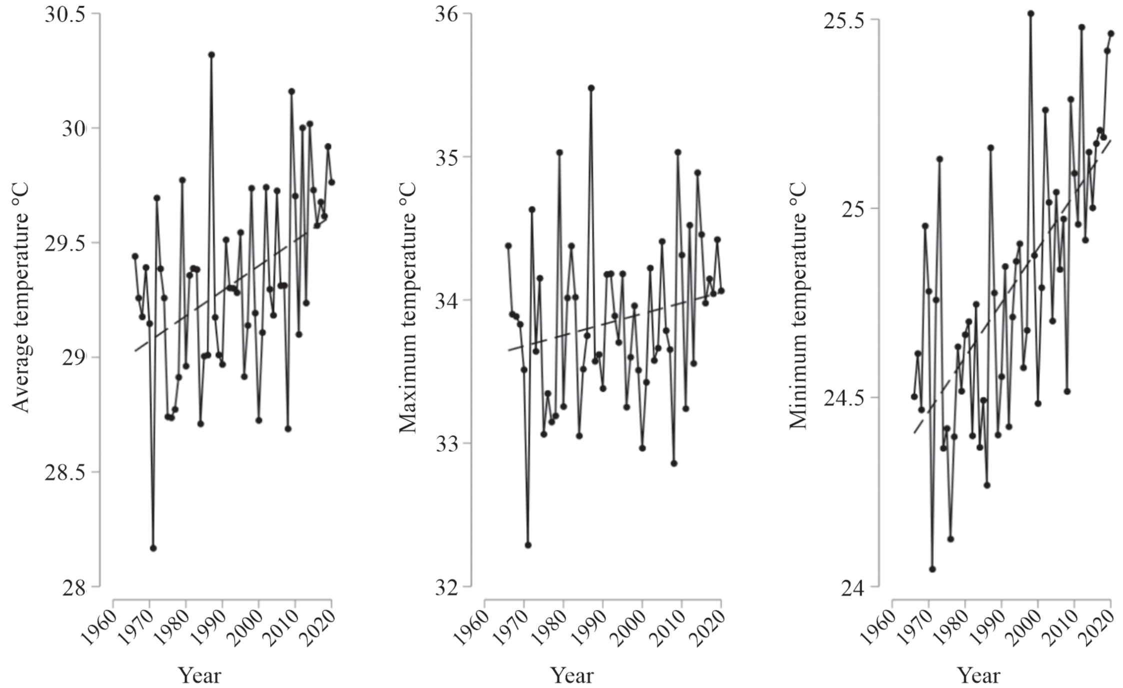
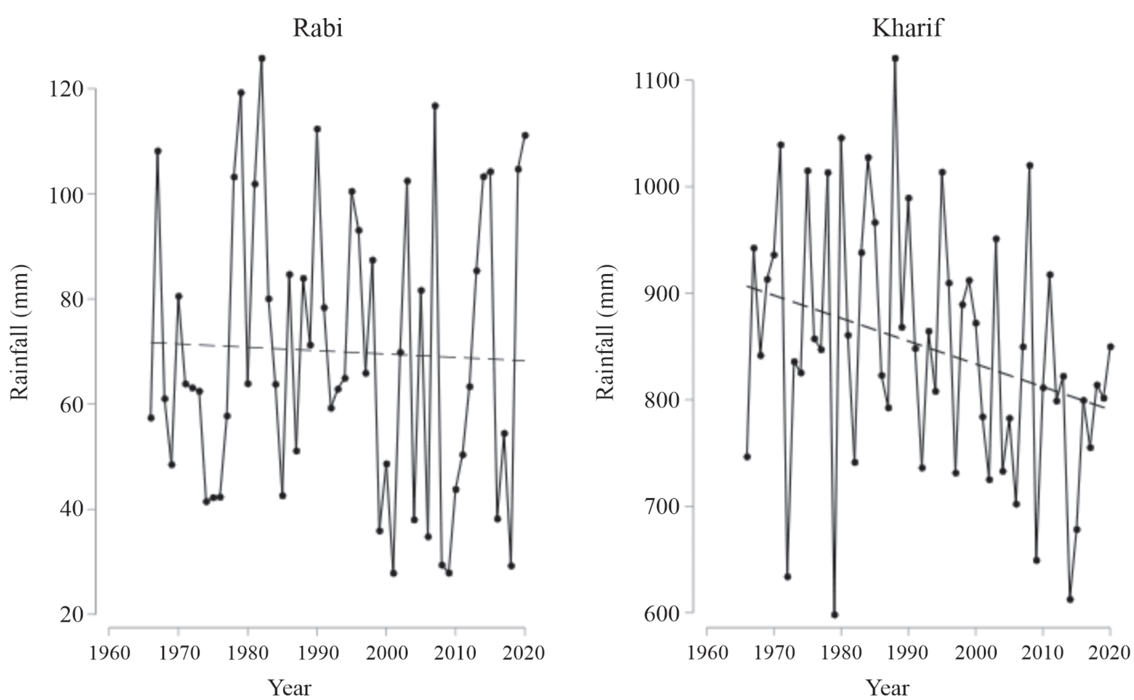


Figure 2 The Trend in average, maximum and minimum temperature during the *kharif* season in IGP: 1966-2020



---- trend line

Figure 3 The trend in rainfall during rabi and kharif seasons in IGP: 1966-2020

Table 3 Panel data regression results for the kharif crops in IGP: 1966–2020

Variable	Paddy	Maize	Cotton	Pearl Millet
Rainfall	0.00010442***	-0.000433***	-0.0001178	0.0002462
$(Rainfall)^2$	-2.000e-08***	7.000e-08***	0.00000013	-2.500e-07**
T_{min}	-0.22211702*	-0.12241684	-0.57826991	0.44515939
$(T_{min})^2$	0.00441408	0.00185022	0.01242192	-0.00730682
T_{max}	0.49202035***	1.4714015***	2.4566395***	1.276835***
$(T_{max})^2$	-0.009057***	-0.022589***	-0.034236***	-.0212832***
Rainfall ×Irrigation	2.000e-07***	3.650e-06***	0.00000109	-0.00000123
T_{min} × Irrigation	0.00001603	0.00059056	-0.00056665*	0.00057463
T_{max}.× Irrigation	-0.00001592	-0.00035093	0.00031385*	-0.00010766
Time (year)	0.02468672***	0.02390991***	0.01808087***	.02104227***
Constant	-52.3911***	-69.2011***	-74.343***	-67.4653***
District FE	Yes	Yes	Yes	Yes
No. of observations	4920	4323	758	2882
R^2	0.68	0.50	0.29	0.51
Adj R^2	0.67	0.49	0.26	0.50

Note *** p<.01, ** p<.05, * p<.1, Standard errors are within the parentheses

Table 4 Panel data regression results for the rabi crops in IGP: 1966–2020

Variable	Wheat	Sugarcane	Chickpea	Rapeseed & Mustard
Rainfall	-0.000193	0.000345***	0.000997***	-0.00059***
$(Rainfall)^2$	5.500e-07**	-1.700e-07***	-3.600e-07***	1.000e-06***
T_{min}	0.183321***	0.0282898	0.073502	0.1357403**
$(T_{min})^2$	-0.006581***	-0.0006035	-0.0006761	-0.006532***
T_{max}	-0.0512756	0.151266***	1.4323567***	0.05506113
$(T_{max})^2$	0.0005833	-0.002618***	-0.021630***	-0.0000029
Rainfall× Irrigation	-8.500e-07**	-6.400e-07**	-0.0000036	0.0000012
T_{min} × Irrigation	-0.000187***	-0.000271*	0.0033598**	-0.0002823***
T_{max} ×Irrigation	0.0001312***	0.000193**	-0.0020248**	0.0001688***
Time (year)	0.018294***	0.0123998***	0.0087687***	0.0207478***
Constant	-36.1231***	-25.773***	-43.13251***	-43.81861***
District FE	Yes	Yes	Yes	Yes
No. of observations	4946	4015	2497	4284
R^2	0.75	0.46	0.21	0.55
Adj R^2	0.74	0.45	0.19	0.54

Note *** p<.01, ** p<.05, *p <.1, Standard errors are shown within the parentheses

time-invariant location-specific factors that could be correlated with climate variables. The regression coefficients of time (year) are positive and significant for all the crops, indicating positive and significant effects of changes in infrastructure, technological factors, farm-level adjustments in agronomic and cropping practices and human capital over time.

The coefficient of rainfall has been found positive for paddy but negative for maize and statistically insignificant for cotton and pearl millet among kharif crops. The same in the case of rabi crops indicates that the coefficient of rainfall is positive and significant for sugarcane and chickpea while that of rapeseed & mustard is negative and significant, but in the case of wheat, it is insignificant. This may be because wheat is cultivated under assured irrigation conditions in the rabi season. The quadratic term of rainfall has been found significant in most of the crops, meaning that its effect is non-linear with excess rainfall having a damaging effect in the case of paddy, pearl millet, sugarcane and chickpea, whereas, it has a positive effect on the yield of maize, wheat and rapeseed and mustard. The interaction term between irrigation and rainfall has a positive and significant effect in the kharif season and a negative and significant effect in the rabi season.

The coefficient of maximum temperature has shown a positive and significant effect on the yield of kharif as well as rabi crops. On the other hand, a rise in minimum temperature has revealed a significant and positive impact on the yield of most crops. Similarly, in the case of maximum temperature, quadratic term coefficients are significant and negative, except for chickpea, which indicates the damaging effect of rise in maximum temperature on crop yield.

The coefficients for interaction between maximum temperature and irrigation have mostly been found positive and significant, which indicates the supportive effect of irrigation on crop yield in the case of a rise in maximum temperature, whereas in the case of interaction between minimum temperature and irrigation, the coefficients have been found mostly non-significant in the kharif season, except in cotton, where it has shown a negative effect. However, in the case of rabi crops, the interaction has revealed negative and significant effects on all the crops, except chickpea, where it has shown a positive and significant effect.

Marginal effects

The analysis on marginal effect is useful in examining the contribution made of each input to crop yield (Coster, and Adeoti, 2015; Jyoti, and Singh, 2020). The marginal effects of temperature and rainfall were calculated to measure the exact relationship of crop yield and weather variables at their mean values. The variations in crop yield due to 1 ^{o}C increase in temperature and 1 mm rise in rainfall were studied using the equation (2). The expected marginal impact of a single climate variable, Xi on crop yield evaluated at the mean level (Kumar, and Sidana, 2019):

$$E\,[\partial\,\Pi/\partial X_i] = \alpha_{1,i} + 2\alpha_{2,i} * E[X_i] \quad \ldots(2)$$

Where, $E\,[\partial\,\Pi/\partial X_i]$ represents the expected marginal impact of climatic variable X_i on crop yield, the coefficient $\alpha_{1,i}$ and $\alpha_{2,i}$ are coefficients of linear and quadratic terms in the equation, respectively. $E\,[X_i]$ is the expected value of the climatic variable X_i and subscripts i represent the ith climatic variables (temperature or rainfall).

It can be observed from Table 5 that a rise of 1 °C in minimum temperature in the kharif season reduces the yield of paddy by 2.4 per cent, maize by 3.1 per cent, and cotton by 10.0 per cent and increases the yield of

Table 5 Marginal effects of temperature and rainfall on yield of rabi and kharif crops in IGP: 1966–2020

Variable	Kharif Crops			
	Paddy	Maize	Pearl Millet	Cotton
Min. temp	-0.02429***	-0.03113**	0.10400***	-0.09994***
Max. temp	-0.105627***	-0.01742	-0.12527***	0.13798***
Rainfall	0.00008***	-0.00028***	-0.00008*	0.00010
Irrigation	0.00003	0.00545***	0.00914***	-0.00048
Year	0.02469***	0.02391***	0.02104***	0.01808***
	Rabi Crops			
	Wheat	Chickpea	Rapeseed & Mustard	Sugarcane
Min. temp	-0.02961***	0.06051***	-0.04456***	-0.00168
Max. temp	0.00263	-0.04296***	0.05865***	-0.01127
Rainfall	-0.00020***	0.00037***	-0.00033***	0.00005***
Irrigation	0.00104***	0.00043	0.00101***	0.00044**
Year	0.01829***	0.00877***	0.02075***	0.01240***

Note *** p<.01, ** p<.05, *p <.1

pearl millet by 10.4 per cent. However, the effect of an increase in the maximum temperature reduces the yield of paddy by 10.56 per cent, maize by 1.74 per cent, pearl millet by 12.53 per cent, and increases the yield of cotton by 13.80 per cent. The net effect of change in temperature has been observed to be positive for cotton (3.8%) but negative for other kharif crops, viz. paddy (-13.0%), maize (-4.9%) and pearl millet (-2.1%). Among the kharif crops, the yield of paddy has been found to be affected severely, however, the cotton yield has shown gains from changes in temperature.

Among the rabi crops, a rise in minimum temperature has a significant and negative effect on the yield of wheat (-3.0%) and rapeseed & mustard (-4.46%). In comparison, the yield of chickpea gained (6.1%) significantly by an increase in minimum temperature. In the case of sugarcane, no significant impact of the rise in minimum temperature was observed. However, the rise in maximum temperature has shown a significant and positive impact on the yield of rapeseed & mustard (5.90%), and a negative and significant impact on the yield of chickpea (-4.30%). No significant impact of rise in the maximum temperature was observed in the case of wheat and sugarcane. The net effect of a rise in temperature on the yield of rabi crops was observed to be positive in the case of chickpea (1.76%) and rapeseed & mustard (1.41%) and negative in the case of wheat (-2.70%), while the impact on sugarcane remained negative (-1.3%) but insignificant.

The marginal effect of rainfall on the yield of kharif crops was negative and significant for maize (-0.01%) and pearl millet (-0.01%) and positive for paddy (0.01%) and had no significant effect on the yield of cotton. In the case of rabi crops, an increase in rainfall had a positive and significant effect on the yield of chickpea (0.04%) and sugarcane (0.01%) while a negative and significant effect on the yield of wheat (-0.02%) and rapeseed & mustard (-0.03%). The positive effect of an increase in rainfall in rainfed crops like chickpeas and water-guzzling crops like sugarcane is on the expected line as sugarcane requires more water for their growth and chickpea, a rainfed crop grows well in case of light rainfall. Also, the negative effect of increase in rainfall on irrigated and water-logging-sensitive crops like wheat and rapeseed & mustard are as per expectation. Wheat crop growth suffers in the case of water logging and also the rapeseed and mustard and hence the result is on the expected line. Overall, the effect of an increase in rainfall on the yield of crops was very low. The effect of irrigation on the yield of crops in both the rabi and kharif seasons was positive and significant, except for paddy, cotton and maize, where no significant effect was observed. These results suggest that the impact of climate change on crop yield in the IGP will be largely driven by the changes in temperature. Also, the impact of climate change on agricultural productivity varies among crops.

A study (Sinha, and Swaminathan, 1991) has estimated that a 2 °C increase in temperature could decrease the rice yield by about 0.75 t/ha in the high-yield areas and by 0.06 t/ha in the low-yield coastal regions. Under the controlled condition experimentation, it was assessed that a rise of 1 °C in temperature could reduce the yield of wheat by 8.1 per cent; of rice by 5.4 per cent, and of maize by 10.4 per cent (Mall et al., 2006). The gross value output of agriculture in the country would fall by 4 per cent if the temperature during the rabi season rises by 1 per cent and by 9.2 per cent if it rises by 1 per cent during the kharif season (Birthal et al., 2015). Most of the studies using the panel data approach have also revealed that climate change would negatively affect the major food crops like rice, wheat and maize through a rise in the temperature (Birthal et al., 2014; Kumar, and Sidana, 2019; Ramarao et al., 2022). Another study (Singh et al., 2019a) reported a negative effect of climate change on major food crops, viz. rice, wheat, kharif maize, sorghum and cash crops like cotton and sugarcane, and positive effects of climatic factors on rapeseed and mustard, barley and pearl millet. The positive impact of climate change on the yield of some crops has been reported by many authors. A positive impact of climate change has been reported on the yield of rapeseed and mustard in India (Birthal et al., 2014; Ramarao et al., 2022). The chickpea grain yield could increase by 11 per cent due to the positive effects of rising CO_2 concentration which slightly increased water-use efficiency (0.03%) based on an increase in the evapotranspiration (10.9%) and mean temperature (3.4%) and decreased in the chickpea growing period (21.9%) (Amiri et al., 2021). An increase in cotton yield has been reported due to climate change when sufficient soil fertilizers and adequate water were provided in Africa (Amouzou *et al.*, 2018). It was found that a 1 °C rise in minimum temperature increased cotton yield by 20.8 per cent. On the other hand, a 1 °C rise in maximum temperature decreased cotton yield by 10.3% (Sharma et al., 2022). However, the irrigated cotton production did not suffer from climate change if CO_2 effects were considered, whereas rainfed production was found more sensitive to varying climatic conditions (Jans et al., 2021).

The findings indicate that raising the yields of most crops will be a great challenge under the climate change if the proper adaptation strategies are not employed. To avoid negative impacts on several crops that are important to ensure food security, climate-resilient technologies must be adopted.

Projections of impact of climate change on crop yield

It is crucial to estimate the impact of future changes in climate on crop yield in future. This section projects the likely changes in yields of particular crops in response to an increase in temperature for different time periods, viz. 2040, 2050 and 2080 using the Equation (3):

$$\Delta Y = \left(\frac{\partial Y}{\partial R}\right) * \Delta R + \left(\frac{\partial Y}{\partial T}\right) * \Delta T * 100 \qquad \ldots(3)$$

Where, ΔY denotes the change in crop yield, ΔR denotes the change in rainfall, and ΔT shows the change in temperature and $\left(\frac{\partial Y}{\partial R}\right)$ and $\left(\frac{\partial Y}{\partial T}\right)$ are their marginal effects estimated from the model.

The projected changes in the annual average daily minimum and maximum temperature have been utilized from the CORDEX South Asia multi-RCM reliability ensemble average estimate of projected changes under RCPs 4.5 and 8.5 scenarios in crop yields for 2040, 2050 and 2080 in India (Singh *et al.*, 2020). Further, a variation of 7%, 10% and 12% in rainfall has been assumed by 2040, 2050 and 2080.

Projected impact

Table 6 presents the projected impact of climate change on crops in India. It indicates that the yield of paddy would decline most due to climate change in all the projected time periods. By the year 2080, the paddy yield would be lowered by 30.48 per cent due to significant changes in climate under the RCP 4.5 climate scenario. This would be followed by maize whose yield would decline by 12.51 per cent; wheat by 5.73 per cent, and pearl millet by 1.43 per cent, by 2080 under RCP 4.5 scenario. This indicates the climate change resistance ability in the millets. The yield of sugarcane would decline by about 2.96 per cent by

Table 6 Projected change in crop yield by 2040, 2050 and 2080 in IGP

(value in %)

Crop	Projected yield with RCP 4.5 climate scenario			Projected yield with RCP 8.5 climate scenario		
	2040	2050	2080	2040	2050	2080
	Δ MinT =1.75	Δ Mint =2.14	Δ MinT =2.63	ΔMinT =2.05	Δ MinT =2.60	Δ Mint =4.43
	Δ MaxT =1.50	Δ MaxT =1.81	Δ MaxT =2.29	Δ MaxT =1.83	Δ MaxT =2.30	Δ MaxT =3.94
	Δ R=(+/-)7%	Δ R=(+/-)10%	Δ R=(+/-)12%	Δ R=(+/-)7%	Δ R=(+/-)10%	Δ R=(+/-)12%
Kharif crops						
Paddy	-20.04	-24.23	-30.48	-24.25	-30.53	-52.28
Maize	-8.26	-10.09	-12.51	-9.76	-12.38	-20.99
Pearl millet	-0.65	-0.50	-1.43	-1.66	-1.85	-3.38
Cotton	3.28	3.69	5.44	4.83	5.85	10.21
Rabi crops						
Wheat	-4.93	-6.06	-7.43	-5.73	-7.30	-12.33
Chickpea	4.41	5.55	6.52	4.80	6.23	10.33
Rapeseed & Mustard	0.77	0.75	1.31	1.36	1.57	2.97
Sugarcane	-1.95	-2.35	-2.96	-2.37	-2.98	-5.12

Source Authors' estimation
The change in rainfall for the future projections, the values were accessed from Singh *et al*. (2019a)

2080. Moreover, the yield of chickpeas, cotton, and rapeseed-mustard are expected to increase by 6.52 per cent, 5.44 per cent and 1.31 per cent, respectively, by the year 2080 under the RCP 4.5 scenario. If the climate does not change significantly, the yield losses or gains for different crops may be smaller. The climate impacts would be more severe in the long run as compared to the short- run. The impact of climate change may not be as severe as projected in the study in the long run too because of continuous adaptation.

The decline in yields of wheat and rice could have been partly due to changes in weather in the Indo-Gangetic Plains (Agarwal et al., 2004). Adopting modern technologies such as mixed cropping patterns, changes in planting dates, and irrigation methods can prove to be an effective measure to reduce the negative impact of climate change on crops (Kumar et al., 2016). The use of chemical fertilizers should be minimized to maintain the quality of water and soil which would reduce the impact of climate change in the near future (Singh et al., 2019). Access to credit facilities should be provided to the farmers to make use of appropriate farming technologies, organic farming, high-yielding variety seeds and better irrigation facilities (Kumar et al., 2016) Singh et al., 2019). The adverse impact of climate change can be reduced by taking proactive adaptation measures. Under the scenario of evolving technologies and climate change, it is important to introduce crops that may cope up with fluctuating temperatures and other climatic factors.

Conclusions

The study has estimated the impact of climate change on the yield of crops in the Indo-Gangetic Plains of India and has made projections for 2040, 2050 and 2080. It has been indicated an increase in the mean temperature and a decline in the rainfall over the period in IGP. This has revealed a negative impact on agricultural productivity in major crops and it has posed a big challenge to increase crop yield in the future without appropriate adaptation measures. The projected impact on the yield of crops has revealed that most of the crops, particularly paddy, would be severely affected. The pearl millet would be least affected due to climatic changes which indicates its climate-tolerant ability. On the other hand, the rapeseed and mustard, cotton and chickpeas could show a positive impact. The adverse impact of climate change can be moderated/reduced by taking proactive adaptation measures such as adoption of improved stress-tolerant varieties of crops, diversification of cropping system, changes in planting dates, mechanization of farm operations and improvements in irrigation methods. These measures could prove effective in reducing the negative impact of climate change on productivity of crops in the IGP region of India.

Acknowledgements

This paper is based on the research project 'National Innovation on Climate Resilient Agriculture (NICRA)'. The authors are highly thankful to the Director, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi, for providing facilities to conduct the study and NICRA for funding the project.

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Received 9 March 2024 Accepted 17 June 2024

Agricultural Economics Research Review 2024, 37 (1), 59-78
DOI: 10.5958/0974-0279.2024.00010.7

Contract farming, farmers' income and adoption of food safety practices: Evidence from remote areas of Nepal

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Abstract In this paper we study the case of contract farming for exports with farmers in remote hilly areas of Nepal. The prospect for contract farming in such areas with accessibility issues owing to underdeveloped markets and lack of amenities is ambiguous. On the one hand, contractors find it difficult to build links in these cases particularly when final consumers have quality and safety requirements. On the other hand however, remoteness makes the contracts more sustainable. The latter happens if there are product specific quality advantages because of agro-ecology and more importantly due to lack of side selling opportunities. At the same time concerns remain about monopsonistic powers of the buyers when remotely located small farmers do not have outside options. This study hence quantifies the benefits of contract farming on remotely located farmers' income and compliance with food safety measures. Results show that contract farming is significantly more profitable (58% greater net income) than independent production, the main pathway being higher price realization along with training on practices and provision of quality seeds.

Keywords Contract farming, ginger, income, food safety, small farmers, Nepal

JEL codes Q12, Q13, Q17, Q18

Introduction

Contract farming (CF) has emerged as an important institution to promote agricultural modernization and commercialization. It has long been prevalent in developed countries and in recent decades, has spread widely in the developing countries as well (Wong et al., 2014). The CF is one of the important institutional solutions for overcoming the market-related transaction costs. When transaction costs are high, or markets fail because of such factors as asymmetric information, mitigating them might create a need for non-spot transactions through CF. With quality and safety issues in the final product, the ability of the spot markets to deliver an efficient solution is in question, mainly due to the problems of asymmetric information.

Barrett et al. (2011) have shown that in contractual arrangements in agriculture several factors matter, such as agro-ecological suitability, nature and type of contract and these could determine the level of production as well as the quality of produce. Second, the contractor must factor in costs such as those incurred when picking up agricultural commodities and transaction costs based on institutional conditions that may influence the likelihood of contract compliance.

In this context, the farmers in remote areas could be at a disadvantage. Concomitantly, such farmers can be attractive to the contractors due to lack of local markets in the area and this could make enforcement of contracts easier with rare opportunities for side selling. The remoteness of an area can also lead to monopsony power, and buyers can exploit small farmers in both selection of the contracts as well as in sharing the value upon their selection. We study a case of CF in ginger in the remote areas of Nepal.

The ginger farming is practiced in Nepal largely in the remote hilly areas, characterized by lack of vertical coordination. This study assesses the effects of CF on farmers not only from the perspective of net operating profits but also in terms of delivering good agricultural practices (GAP). These issues are important because in the remote areas, the questions of gains for farmers (amid fears about buyers' monopsony powers) and sellers' potential lack of capacity to deliver on quality and safety are quite pertinent.

The main research questions addressed in this paper are:

(i) What are the factors that determine selection of farmers into contracting in remote locations? Specifically, is there a positive or a negative selection where the ones selected into the contracts are likely to have worse outcomes relative to those not in the contract?

(ii) Does CF increase incomes of the farmers significantly in remote areas of Nepal,? If yes, what is the extent of gains from contracting vis-à-vis independent production and selling of ginger?

(iii) Headed for exports markets, does CF deliver on food safety and the GAP?

The remote ginger-producing areas can be provided a better access to land and could have comparatively good agro-climatic conditions, but these could be in a disadvantageous position because of higher marketing costs (related to transportation, costs of price discovery). Besides, farmers may lack the capacity (owing to lack of information and skills) to deliver a quality product. As per Barrett et al. (2011), contractors in India deliberately chose remote areas to prevent side selling. Kulkarni and Grethe (2009) also find that farmers in India living far from the credit institutions with less opportunity to find subsidiary jobs outside agriculture, participated more in the contracting. Similarly, Manorom et al. (2011) find benefits of CF to smallholders growing cabbage, maize, and sugarcane in diverse conditions in Lao People's Democratic Republic.

Cai et al. (2008) have indicated that in Cambodia the progressive farmers living near the highways tended to join CF first but terminate the contract prematurely also. But, in lands closer to the mountains where public-sector organizational capacity was the weakest remained longer under the contract. The farmers close to main roads tended to default on contracts more often than others. Also, relatively uncontaminated land in the remote areas lent itself to production of safe and better-quality rice. Elsewhere, experiences in the remote areas of East Africa, (for example, sugarcane in western Kenya and tea in Tanzania) suggest that CF in the underdeveloped areas acted as growth poles (Glover, 1994).

Apprehensions remain about the smallholders in remote areas being exploited by the large firms. The policymakers in Nepal, having several remote areas, face the question of whether to promote, regulate, or prevent CF (Nepal, Ministry of Agricultural Development, 2015). Nepal is drafting a law on CF and is seeking information on the outcomes from the existing cases (IFPRI, 2016). This study may provide useful information in this context. It is based on the primary data collected from more than 600 households, comprising both contracted and independent farmers from the remote hill districts of Pyuthan, Palpa, and Arghakhanchi in Western and Mid-western development regions of Nepal.

Given the cross-sectional data and the identification issues, we have used the instrumental variable (IV) approach, the method in Lewbel (2012) and propensity score matching method. The Lewbel approach is a modification over the standard IV method as it addresses inconsistency in the IV estimates arising from invalid instruments. The results from matching methods are helpful in establishing the robustness of study results.

The results show that participation in CF is unrelated to a farmer's land size and the tribal farmers have a significantly greater likelihood of joining CF. The results further show that for these farmers located in the remote areas with lesser access to markets, CF is associated with 56% higher net profits. The findings also highlight the differential gains across ginger farmers as per size of the farm.

The paper is organized as follows. Section 2 provides a brief background of the Nepalese ginger sector and some details about contracts in it. Section 3 describes the survey data and the methodological approach followed in the study. Estimation results are presented and discussed in Section 4, while the concluding section provides some policy implications.

Ginger farming and contracts in Nepal

Nepal is the fourth-largest producer of ginger in the world (9% share in 2017), after India (35%), China (18%) and Nigeria (12%). However, the yield of ginger is the highest in Nepal (12.3 tons/ha), followed by China (10.6 tons/ha), India (6.4 tons/ha) and Nigeria (5.3 tons/ha). The agro-ecological suitability of hills for ginger farming, which contributes 70 per cent of production, is one of the factors behind a comparative higher yield. The ginger is an important cash crop in the hill-regions of Nepal; its area and production have increased by around 8 and 10-times, respectively during 1991 and 2017.

The ginger exports from Nepal increased from 2,461 tons in 1991 to 34,947 tons in 2013, registering an annual growth rate of 13%. However, the annual exports in value-terms grew at 2.9%. A big share of exports goes to India; and after processing, it is also exported to Japan, Dubai, and Europe.

The quality of ginger, judged primarily by its fibre-content, is classified as superior or inferior. The varieties with very low fibre-content are classed as superior and are locally known as *boshe*. The varieties with high fibre-content are considered inferior and are called *nashe*. Though the superior varieties fetch higher prices, the cultivation of inferior varieties is more common in Nepal. The superior varieties are preferred for producing industrial products like ginger oil, while the spice industry prefers fibrous *nashe* varieties for producing ginger powder.

On comparing the contract and non-contract farmers, we find that a larger fraction of contract farmers cultivates both the varieties. However, the inferior variety is grown by almost equal proportions of contract and non-contract farmers (Table 1).

Table 1 Distribution of contract and non-contract farmers for cultivation of inferior and superior varieties of ginger

Seed variety	Contract farmers	Non-contract farmers
Total sample size	322	283
Nashe (inferior)	207 (64%)	182 (64%)
Boshe (superior)	50 (16%)	53 (19%)
Both varieties	62 (19%)	46 (16%)

Source Authors' calculations based on field survey (2014).
Note Figures within the bracket are %age shares

Structure of contract for ginger cultivation

The contracting farmers have been cultivating ginger even prior to opting contract. The contract between a firm and each farmer is formal/written and is signed annually before crop planting. The contracts generally survive on mutual trust between the contracting parties. The firm's purchase price is determined by a combination of factors: cost of production, quality and local market price. The firm assesses in advance the quantity that each farmer anticipates to supply. The contract assures a minimum price (base price) of NPR 25 per kg, irrespective of the market price, thus insuring to some extent against the market risk. The firm often procures through farmers' cooperatives or associations at the village level.

The contracting firm does not provide physical inputs. However, it provides training on new technologies in seed production, adoption of good agricultural practices (GAP), disease management and production of organic (compost) fertilizer. The firm strives to keep the costs comparable to the non-contract farmers. Over 60% contract farmers use self-produced quality seeds, while the remaining farmers purchase seeds from the cooperatives, who in turn could get it from the contracting firm at cost-price.

Though there is not yet a regulation governing the CF, a breach of contract may be challenged under the general civil law of Nepal. In practice, if there is a breach by side-selling of produce, the company does not renew the contract for the next growing cycle and if the company breaches by not procuring, the farmers refrain from contracting with that firm. Due to repeated interactions, there is an element of self-enforcement for both parties. On an average, the contract farmers have been with the firm for three years, minimum one year to a maximum of 13 years.

The food safety and quality are the crucial factors in CF for ginger exports. Often, Nepal's exports face consignment rejections. In 2016, India, the main importer, banned imports, arguing that Nepal's ginger had high pesticide residues and that Chinese ginger was being exported as the Nepal's product. India's Food Safety and Standards Authority dispatched a circular to all the custom points in India about pesticide residues in the Nepalese ginger.

India's official import requirements stipulate that Nepalese rhizome ginger must be accompanied by a phytosanitary certificate and should be free from weeds, seeds and soil. The food safety analytical report, issued by the Department of Food Technology and Quality Control (Government of Nepal), is mandatory for exporting to India and there is a requirement to clear the pesticide residue tests at border points (Nepal, Ministry of Agricultural Development, 2011).

Further, the contracting firm obtains organic certification for the product from the National Association for Sustainable Agriculture, Australia (NASAA), accredited by the International Federation of Organic Agriculture Movements (IFOAM). It also has certification from the Japanese Agricultural Standard (JAS). A prominent farmer cooperative (Erawati Multipurpose Small Farmers' Cooperative) in Pyuthan, Nepal, which supplies to the firm, also has organic product certification from NASAA. Besides, ginger is prone to contamination with aflatoxin-producing strains of *Aspergillus flavus* if samples contain higher level (12.5 – 25µg/kg) of aflatoxins and for this drying practices are to be followed.

Data and methodology

Through, the primary survey of farm households, data was collected on farm household characteristics, cropping pattern, economics of cultivation, marketing channels, and information on GAP. The survey was conducted during December 2014 in the hill districts of Pyuthan, Palpa, and Arghakhanchi (Figure 1). These districts have a high concentration of contract farmers for Annapurna Organic Agriculture Industry (AOAI). Further, these districts contribute 18% to the area and 12% to the production of ginger in Nepal (Nepal, Ministry of Agricultural Development, 2014). The Western and the Mid-western regions contribute around 45% to the area and 41% to the production of ginger in Nepal.

The AOAI, situated in the Arghakhanchi district, is the sole processor of ginger in Nepal. It produces processed products such as powdered spices (ginger, coriander, garlic, cumin, turmeric, cinnamon, Sichuan pepper, and chili powder); coffee; dried and sliced ginger (*sutho*); and other ginger products such as candy, jam, juice, and pickles. The company is primarily involved in exporting (80% revenue share through exports), The company had contracts with 3,000 ginger farmers from eight districts of the Western and Mid-western development regions earlier, but currently the company has contracts with only 700 farmers, located mainly in the Pyuthan district, followed by Arghakhanchi and Palpa districts.

In the markets that demand food safety, it is common that the firm usually goes for a smaller number of farmers, if traceability and other requirements exist (Narrod et al., 2009). In such cases, a firm initially

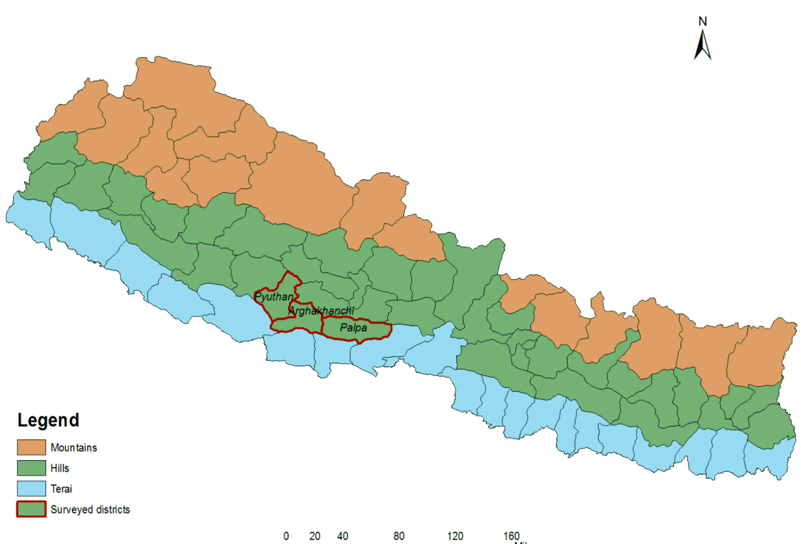


Figure 1 Agro-climatic zones in Nepal and surveyed districts

focuses on a comparatively large number of farmers for contract before optimizing on group sizes and overall number of contract farmers. Later, the firms tend to focus on a limited number of farmers at a fewer geographic locations. The firm had 3,000 contracts in 2010-11, but over a period of five years it targeted higher end-markets and hence, downsized the number of farmers under contract.

For this study, we randomly selected 45 wards from thirteen VDCs in the three districts of Nepal and randomly chose 59 villages for the survey of independent farmers. We listed noncontract ginger-growing households in those villages and randomly chose farmers from there. We surveyed 322 contract farmers and 283 noncontract farmers—chosen randomly from 53 wards under 14 VDCs from the three districts, the share of each district being in proportion to the number of contract farmers. The numbers of farmers from the districts of Pyuthan, Arghakhanchi, and Palpa were 314, 198, and 93, respectively. The VDCs within the districts were also selected based on the presence of contract farmers in ginger production. An approximately equal number of noncontract farmers were randomly chosen in the same or adjacent VDCs in each district. This was done to have a similar soil, agroclimatic environment and physical & marketing infrastructure for the sample contract and noncontract farmers.

The sampling frame for 283 control farmers comprised independent ginger growers from the same village development councils (VDCs) as surveyed for contract farmers or an adjacent VDC, in the three selected districts. The independent growers were selected randomly from villages in the wards within these VDCs. After procuring from the contracting firm a listing of contract farm-households and their addresses, we randomly selected farmers for the survey. We considered a sample of 283 independent farmers, distributed in 3 districts in proportion to the sample of contract farmers. Accordingly, the sample size of noncontract farmers in the districts of Pyuthan, Palpa, and Arghakhanchi was 122, 47 and 114, respectively.

Descriptive statistics

Characteristics of farmer households

The characteristics of contract and non-contract ginger cultivators, shown in Tables 2 reveal that these farmers do not differ significantly in their resource endowments and most of the socioeconomic attributes. The incidence of migration for employment differs significantly across the contract and independent farmers. This difference is important as we have used this as an instrument variable for contracting in the subsequent analysis. The average family size and land size of contract and independent farmers are almost the same (6 members and 0.8 ha, on an average).

The cropping intensity (119%) of independent farmers is higher than that of contract farmers (111%). There is no significant difference in the educational attainments of contract and independent farmers (Table 2). Interestingly, the contract and noncontract farmers differ significantly in terms of their caste affiliations. More than 50% contract farmers belong to the tribal groups (usually more remotely located), compared with 32% noncontract farmers. Further, more than 70% contracted households are small or marginal farmers having less than 1 ha of land.

Costs and returns in ginger cultivation

In Nepal, proper pricing of inputs and outputs is difficult because of incomplete markets and unobserved transaction costs (Barrett, 1997). We have estimated profits by looking at the disaggregated information on costs, constituents of which were collected through pre-survey interactions to minimize the measurement errors. The costs of producing ginger comprise labour (own and hired), rentals and tax on land, seed (including seed treatment), farmyard manure (if used), pesticides (if applied), and rental for machinery (if employed). The postharvest costs are related mainly to transporting the produce to the market. We collected detailed information to get an accurate estimate of costs, especially the costs on labour for activities such as land preparation, manure application, mulch collection, planting/sowing, irrigation, weeding, spraying, harvesting, and winnowing. The farmers' profits were calculated as the difference between the revenue cost and total cost.

Table 3 reports the association of CF with yield, production costs, output prices, and profits. The average yield of ginger is not significantly different between the contract and independent farmers (91 q/ha). Importantly, there is no significant difference in the cost of cultivation also. Keeping the costs comparable, a higher price realization by the contract farmers

Table 2 Characteristics of contract and noncontract cultivators of ginger in Nepal

Characteristics	Contract farmers	Noncontract farmers
Number of observations	322	283
Age of respondent (years)	46 (13.4)	44 (13.7)
Years of education (HH member with highest level)	10.6 (2.7)	10.7 (3.0)
Household size (No.)	6.4 (3.0)	6.3 (4.2)
Size of landholding (ha)	0.80 (0.66)	0.73 (0.64)
Gross cultivated area (ha)	0.89 (0.63)	0.87 (0.66)
Cropping intensity (%)	111 (67)	119 (80)
Irrigated area (% of cropped area)	14.0 (18.7)	12.5 (18.4)
Households having farming as primary occupation (%)	95.7 (20.4)	92.2 (26.8)
Migration for employment (number per household) **	0.9 (1.1)	0.7 (0.9)
Monthly remittance (NPR)	10,020 (13,446)	8,621 (13,798)
Experience in farming (years)	27 (13.4)	26 (13.3)
Number of plots per household	2.6 (4.0)	2.5 (1.6)
Education level		
Illiterate	0.3	1.4
Primary	5.6	4.6
Middle	17.4	17.3
Secondary	61.2	59.0
Graduate & higher	15.5	17.7
Farm size		
Marginal (< 0.5 ha)	40.4	44.2
Small (0.5–1 ha)	30.7	31.1
Medium (1–2 ha)	22.0	17.3
Large (≥ 2 ha)	6.8	7.4
Social groups (castes)***		
General caste	33	44
Dalit castes	14	24
Tribal castes	53	32

Source Authors' calculations based on field survey (2014).

Notes *** and ** represent significance at the 1% and 5% levels, respectively. Figures within the brackets represent standard deviation. HH = household; NPR = Nepalese rupees.

translates into higher profits. On an average, the contract farmers realize 40% higher profits as compared to the non-CF.

Our findings are consistent with Bellemare (2012); Michelson (2013); Miyata et al. (2009); Simmons et al. (2005); Singh (2002); Wainaina et al. (2012); Xu and Wang (2009). It is important to note that more than 70 per cent farmers in these remote areas of Nepal have less than 1 ha of land and they would have lesser prospects without contracting.

The composition of cost is broadly similar across the contract and independent farmers. The labor costs account for more than 30% of the costs for both contract (31.3%) and noncontract (33.8%) farmers (Table 4). Land preparation, harvesting, weeding, and sowing together constitute two-thirds of the aggregate labor costs for both groups. Input costs (predominantly seed cost) account for about 55% of the total costs; however, seed costs make up a greater proportion of overall expenses (54.4%) for contract farmers than for the noncontract farmers (52%).

Table 3 Economics of cultivation of ginger for contract and noncontract farmers in Nepal

Economics of cultivation	Contract farmers	Noncontract farmers	Difference	Percentage difference
Yield (q/ha)	91.0 (33.4)	90.8 (37.5)	0.2*	0.2
Price (NPR/q)	5,576 (1,571)	4,768 (1,044)	808***	16.9
Value of production (NPR/ha)	529,599 (217,219)	439,174 (200,808)	90,425***	20.6
Cost of cultivation (NPR/ha)	217,029 (69,423)	217,752 (73,112)	-723	-0.3
Cost of production (NPR/q)	2,384 (1,078)	2,399 (1,057)	-15***	-0.6
Profit (NPR/ha)	312,570 (216,916)	221,422 (198,640)	91,148***	41.2
Profit (NPR/q)	3,434 (1,727)	2,440 (1,331)	994***	40.7

Source Authors' calculations based on field survey (2014).
Notes *** and * represent significance at 1% and 10% levels, respectively. Figures in bracket represent standard deviation. NPR = Nepalese rupees; Q = quintals.

Table 4 A Composition of cost of cultivation of contract and noncontract farmers of ginger in Nepal

Costs	Share in total cost of cultivation, %	
	Contract farmers	Noncontract farmers
Labour costs		
Land preparation activities	5.5	5.9
Farmyard manure application	3.9	4.2
Mulch collection	3.7	4.1
Planting/sowing	4.9	5.2
Irrigation	0.0	0.1
Weeding	4.9	5.3
Spraying	0.2	0.3
Harvesting	5.4	5.6
Cleaning	2.8	3.1
Input costs		
Seed	54.4	52.0
Manure	2.3	2.5
Costs on hiring bullocks and farm equipment		
Bullocks (ploughing)	3.4	3.5
Farm machineries	0.2	0.4
Fixed costs		
Rental value of owned land	4.3	4.1
Land revenue/tax	0.1	0.1
Other costs	0.2	0.2
Cost on transportation of produce to market	3.7	3.2

Source: Authors' calculations based on primary survey data (December 2014).

Adoption of food safety measures in ginger cultivation

To assess compliance with food safety practices, we developed a 'food safety index' at the farm level. The survey gathered information from farmers on adoption of 45 distinct good agricultural practices (GAP), including record keeping and site management, propagation material, nutrition management, water management, plant protection, and postharvest management. We sought an objective response from the farmers on whether they follow each of the 45 practices; we summed up all responses given by a farm household to create an aggregate score of good practices. This served as a proxy for compliance with food safety measures (FSMs). The aggregate score for adoption of good practices for the kth household is given as per Equation (1):

$$S = \sum_{j=1}^{45} F_{jk} \quad \text{...(1)}$$

where, F_{jk} represents jth good agricultural practice followed by the kth household.

Then, the scores were standardized, and food safety index (FSI) was calculated as per Equation (2):

$$\text{FSI} = \left(\frac{S_A - S_L}{S_M - S_L}\right) \times 100 \quad \text{...(2)}$$

Where, S_A is the household's actual score, S_L is the minimum score and S_M is the maximum score among surveyed households.

Kumar et al. (2011, 2017) have used a FSI index for assessing the compliance with FSMs in milk production in both India and Nepal. The average level of compliance, based on FSI, is presented in Table 5. The CF appears to have a positive impact on the adoption of FSMs with contract farmers, adopting 33% of the FSMs compared to 28% for independent farmers. Moreover, the compliance varies considerably among both independent and contract farmers and is positively related to land size.

The average FSI scores, however, mask the exact level of compliance within a category of farmers. Table 6 reports the frequency distribution of farmers by the FSM compliance. We have found that 47% contract farmers and 51% independent farmers were not following even 30% of the recommended practices (i.e. were low adopters). Further, high adopters (following 60% or more practices) were small in numbers —7.1% of contract farmers and significantly lower 2.1% independent farmers. Table A1 gives a list of good agricultural practices studied in the questionnaire.

Among the FSM, plant protection practices were the least adopted by both the categories of farmers (Table 7). In propagation material, nutrition management and plant protection, FSI values for contract and noncontract farmers differ statistically at 1% level. In

Table 6 Distribution of farmers by level of adoption of food safety practices

Food Safety Index (FSI)	% of farmers	
	Contract	Noncontract
< 30 (Low)	47.2	50.9
30–60 (Medium)	45.7	47
≥ 60 (High)	7.1	2.1

Source Authors' calculations based on field survey (2014).
Note FSI = Food Safety Adoption Index

Table 5 Status of adoption of food safety practices in ginger cultivation

Land size category	Contract farmers			Noncontract farmers		
	FSI (%)	S.D.	CV (%)	FSI (%)	S.D.	CV (%)
Marginal (< 0.5 ha)*	29.8	16.3	54.8	26.3	12.7	48.1
Small (0.5–1 ha)***	34.5	17.6	51.1	27.7	13.8	49.9
Medium (1–2 ha)	35.7	20.5	57.5	32.4	14.6	45.0
Large (≥ 2 ha)*	37.5	22.9	61.3	27.0	15.2	56.3
All***	33.1	18.3	55.5	27.9	13.7	49.1

Source Authors' calculation based on field survey (2014).
Notes *** and * represent significance at 1% and 10% levels, respectively. CV = coefficient of variation; FSI = food safety adoption index; S.D. = standard deviation.

Table 7 Status of adoption of different components of food safety practices by ginger farmers

Dimension	Food safety adoption index	
	Contract farmers	Noncontract farmers
Record keeping & site management	32.3 (27.6)	30.0 (25.9)
Propagation material and nutrition management***	14.5 (19.1)	9.6 (12.9)
Water management	14.4 (22.1)	12.7 (20.5)
Plant protection***	12.3 (15.7)	6.7 (11.2)
Postharvest management*	45.6 (22.5)	42.3 (20.8)

Source Authors' calculations based on field survey (2014).
Notes *** and * represent significance at 1% and 10% levels, respectively. Figures within the brackets represent standard deviation.

postharvest management, the two differ statistically at 10% level of significance. Though the average FSI value is higher for contract farmers, nonetheless all FSI values are low in absolute terms, with the exceptions of practices related to record keeping and site management, and those relating to postharvest management.

Econometric analysis of the impact of CF

In this section, answers on two specific research questions have been found. The first was: what characteristics of households were associated with participation in the CF. Note that we looked at it as a subject of participation and not of selection, because several characteristics that we observed would be different at the time of selection. The second question was what was the impact of CF on profits of farmers and adoption of FSM, considering their remote location and the buyers possible monopsonistic market power.

One of the problems in the CF literature is the identification of causal impact of CF on farm profits. The observed and unobserved characteristics such as skills in farming or social connectedness that result in a positive or negative selection into CF are also likely to influence profits. Alternatively, participation in the CF is usually not random but is based on specific characteristics, including location. The possibility of omitted variables implies that the simple linear estimates of the effects of contracting on profits can be biased.

To address the nonrandom nature of participation in the CF, several studies have used a two-step procedure (Bellemare, 2012; Ito et al., 2012; Miyata et al., 2009; Simmons et al., 2005; Wang et al., 2011) in assessing the impact of CF on farm income. Without the benefit of a randomized assignment of farmers into contracts and given that unobserved characteristics can play a role in the decision-making on participation in a contract, we relied on the instrumental variables (IV) technique. An ideal IV should not correlate with the dependent variable in Equation (3); however, it should be correlated with the dummy variable . Additionally, the variable should not be from the vector of farm and operator characteristics.

It is indeed difficult to find an ideal instrument in this setting. When unit profit is dependent variable (see Equation 3), we can identify the instrumental variables— (i) migrants per household members; and (ii) interaction of average price in a ward and proportion of contract farmers by caste in a ward (excluding the specific household). For food safety index equation, the IVs used are: (i) number of household members migrated for employment per household and proportion of migrants in a VDC[1]; and (ii) interaction of average price in a ward and proportion of contract farmers by caste in a ward (excluding the specific household).

Following Lokshin et al. (2010), we have included a specification comprising "proportion of migrants in a ward/VDC" as an instrument in the regression model. In the case of output price, we have used the IVs: (i) migrants per household member; and (ii) interaction of average price in a ward and proportion of contract farmers by caste in a ward (excluding the specific household). The migrants generally are in far off places while ginger marketing takes place locally. The network effects, if any in the ginger markets leading to better prices or lower prices of inputs are likely to be muted.

[1]We thank the anonymous referee for this suggestion.

The motivation for the instruments is the following: Migration for employment by male members in a family is quite prevalent in the hill areas of Nepal. To the extent that possibility of remittance provides a safety net, we find from our surveys that the decision to contract is more likely among the families with migrants. The IV 'migrants per household member' is determined by dividing the number of household members who have migrated for employment with the total number of family members in the household. The share of migrants should not affect the profit from contracting in the ginger directly.

In the first stage, the dependent variable is binary (farmer in a contract = 1, otherwise = 0), and the independent variables are a mix of qualitative and quantitative variables. We have used a linear probability model to examine the factors associated with a farmer being in the contract or independent. In the second stage, to assess the impact of CF on farmers' profits/ FSI/output price, the output function can be represented as per Equation (3):

$$\pi_i = \alpha + \delta d_i + \gamma X_i + \varepsilon_i \qquad \ldots(3)$$

Where, π_i is net profit per kilogram or FSI or output price for a farm household engaged in cultivation of ginger, d_i is a dummy variable (= 1 if the farmer is in a contract and 0 otherwise), X_i is a vector of observable farm and farmer characteristics, and ε_i is an error-term. The estimation of Equation (3) using simple ordinary least squares (OLS) may result in biased estimates. The unobserved factors could guide farmers' entry into a contract. Thus, d_i, is likely to be endogenous and could be correlated with the error-term, ε_i.

Further, the IV - interaction of average price in a ward and proportion of contract farmers by caste in a ward (excluding the specific household), highlights the key role played by the average price of ginger received by sample households in a ward (excluding the specific household) and the network effect of same caste members participating in the contract in a ward (excluding the specific household), in motivating a farmer for participating in contract farming. Further, the average price realized by the farmers in a ward (excluding the farmer) weighted by the proportion of contracting farmers by a caste group in a ward can be an instrument because in wards where average prices are high weighted by the proportion of contracting farmers by caste, it can motivate farmers towards the CF. We believe that social proximity based on caste is important in the rural settings of Nepal. The households from the same village might not mingle with each other if they are from different castes, while farmers from different villages within the ward may interact if they belong to the same caste.

We conducted the Hausman test for endogeneity. Even if evidence of endogeneity was not supported in some cases, we applied IV estimation. We also checked for the strength of these instruments at the first stage. The validity of the instruments (when more than one IV is used) was assessed using the Sargan test for over-identification (Table A2). The instruments are valid if the Sargan test outcome is statistically insignificant, and vice-versa. We found that the instrument variables used for profit, FSI and output price equations were valid.

The assumption made for the validity of an instrument in terms of exclusion restriction is difficult to establish. If it does not hold, it would render the IV estimates as inconsistent. To overcome this limitation of traditional IVs, we used the recent approach on technical instruments given by Lewbel (2012). The heteroscedasticity-based identification relies on heteroscedasticity working as a probabilistic shifter, the essential idea to tracing a causal relationship via exclusion restrictions. Practically, this method involves constructing instruments as simple functions of the model's data. This approach can be followed when no external instruments are available, or it can be used to supplement external instruments to improve the efficiency of the IV estimator. The estimators customarily make use of appropriate lagged values of endogenous regressors to identify the model (Lewbel, 2012).

Let Y_1 and Y_2 be observed endogenous variables, X is a vector of observed exogenous regressors, and $\varepsilon = (\varepsilon_1, \varepsilon_2)$ are unobserved errors. Following are the structural models of the form:

$$Y_1 = X'\beta_1 + Y_2\Upsilon_1 + \varepsilon_1 \qquad \ldots(4)$$

$$Y_2 = X'\beta_2 + Y_1\Upsilon_2 + \varepsilon_2 \qquad \ldots(5)$$

This system is triangular when $\Upsilon_2 = 0$ (or when $\Upsilon_1 = 0$). Otherwise, it is fully simultaneous. The errors ε_1, ε_2 may be correlated with each other.

If the endogeneity assumption, i.e. error being not correlated with endogenous variable holds, meaning

E (εX) = 0, the reduced form is identified, but in the absence of identifying restrictions, the structural parameters are not identified. These restrictions often involve setting certain elements of β_1 or β_2 to zero, which makes instruments available. Identification in Lewbel's approach is achieved by restricting the correlations of $\varepsilon\varepsilon'$ with X. This relies upon higher moments.

The parameters of the structural model will remain unidentified under the standard homoscedasticity assumption, i.e. $E(\varepsilon\varepsilon'|X)$ is a matrix of constants. But, when heteroscedasticity related to at least some elements of X is present, identification can be achieved. In a fully simultaneous system, assuming that $cov(X, \varepsilon_j^2) \neq 0, j = 1,2$ and $cov(Z, \varepsilon_1\varepsilon_2) = 0$ for observed Z will identify the structural parameters. Note that Z maybe a subset of X, so no information outside the model specified above is required (see Lewbel 2012 for details). Emran and Shilpi (2012) employed the technique given by Lewbel (2012) in assessing the causal relationship between the extent of market and the pattern of crop specialization in a village economy.

Finally, we employed the propensity score matching approach to gauge the impact of contract farming on unit profit/FSI/price as a test of robustness. The basic idea of matching is to find a large group of control households or households that are like the treatment households in all relevant pretreatment characteristics. We used nearest neighbour and kernel based matching to select the best control matches for each subject in the treatment group.

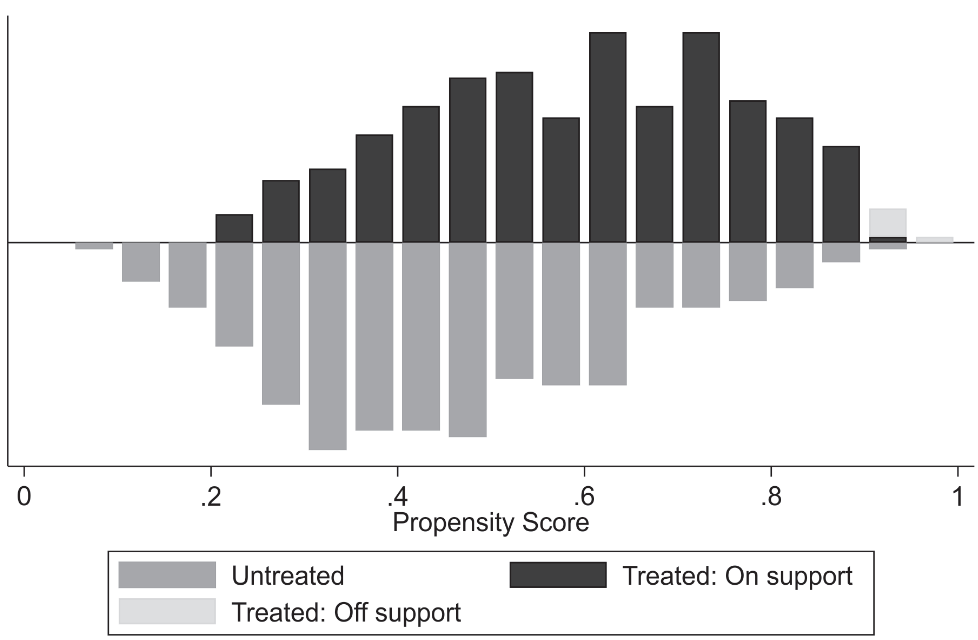
Figure 2 depicts the common support region in the propensity score matching (PSM), using histograms. Figure 3 shows the common support region in the propensity score matching (PSM), based-on the kernel density plots.

Results and discussion

Determinants of farmers' decision to participate in the CF

The independent variables in agriculture are farm, farmer, socio-demographic, and economic characteristics such as age of farmer, gender of respondent, household size, education level, caste, experience in farming, migration, access to a mobile phone, distance from road, and location (district fixed effects) of the village. The choice of explanatory variables was guided by the previous literature on the subject (for example, Bellemare, 2012; Fisher and Qaim, 2012; Kumar et al., 2013; Roy and Thorat, 2008).

The results presented in Table 8 (Columns 3, 5, 7, 9, 11 and 13) show that tribal households and female



Source: Field Survey, 2014

Figure 2 Common support region in PSM using histograms

Table 8 Impact of contract farming on profits — 2SLS approach

Dependent variable: Unit profit in ginger production (NPR/kg)

Variable	Specification 1					Specification 2				Specification 3				
	OLS	2SLS				2SLS				OLS	2SLS			
		Standard IV results		IV with generated instruments and external instruments		Standard IV results		IV with generated instruments and external instruments			Standard IV results		IV with generated instruments and external instruments	
		Ist stage	2nd stage	Ist stage	2nd stage	Ist stage	2nd stage	Ist stage	2nd stage		Ist stage	2nd stage	Ist stage	2nd stage
Contract farming	12.59***		16.979***		14.167***		17.04***		14.17***	12.51***		17.12***		13.69***
	(2.144)		(4.242)		(4.043)		(4.632)		(4.399)	(2.078)		(4.493)		(4.175)
Food Safety Adoption Index										0.0155	0.00256*	-0.00761	0.003**	0.00957
										(0.0885)	(0.0014)	(0.0844)	(0.0014)	(0.0851)
Socio-demographic variables														
Age of household -head	-0.222	0.011	-0.249	0.009	-0.2317	0.0108	-0.250	0.0078	-0.232	-0.200	0.0139	-0.261	0.0086	-0.215
	(0.328)	(0.009)	(0.334)	(0.011)	(0.33193)	(0.00986)	(0.336)	(0.0124)	(0.333)	(0.309)	(0.00961)	(0.314)	(0.012)	(0.316)
Square of the age of household-head	0.00337	-0.00008	0.00346	-0.00006	0.003	-6.48e-05	0.00347	-0.00003	0.00340	0.00320	-8.89e-05	0.00355	-0.00005	0.00329
	(0.00316)	(0.00008)	(0.00316)	(0.0001)	(0.003)	(9.13e-05)	(0.00316)	(0.0001)	(0.00315)	(0.00312)	(9.22e-05)	(0.00310)	(0.0001)	(0.00312)
ln(Household size)	-0.370	0.006	-0.419	-0.028	-0.387	0.00941	-0.420	-0.0214	-0.388	-0.345	0.0151	-0.433	0.0048	-0.367
	(1.846)	(0.054)	(1.994)	(0.051)	(1.887)	(0.0515)	(1.994)	(0.0485)	(1.884)	(1.898)	(0.0520)	(2.040)	(0.0481)	(1.910)
Gender	-0.518	-0.115***	0.148	-0.125***	-0.278	-0.123***	0.157	-0.1347***	-0.278	-0.536	-0.125***	0.172	-0.136***	-0.355
	(1.468)	(0.04)	(1.607)	(0.038)	(1.571)	(0.0416)	(1.630)	(0.0386)	(1.599)	(1.460)	(0.0426)	(1.614)	(0.0397)	(1.580)
ln (Operational land)	2.358**	0.005	2.393**	0.014	2.37**	0.0138	2.394**	0.0225	2.371**	2.311**	0.00602	2.418**	0.012	2.338**
	(1.041)	(0.032)	(1.076)	(0.032)	(1.047)	(0.0329)	(1.078)	(0.0329)	(1.048)	(1.071)	(0.0333)	(1.117)	(0.0305)	(1.067)
Caste														
General	0.440	-0.037	-0.143	-0.065	0.23	-0.0366	-0.151	-0.0655	0.230	0.462	-0.0305	-0.167	-0.0724	0.301
	(2.324)	(0.094)	(2.653)	(0.077)	(2.441)	(0.0974)	(2.648)	(0.0788)	(2.430)	(2.343)	(0.0995)	(2.689)	(0.0803)	(2.430)
Tribal	0.356	-0.02	-0.847	-0.042	-0.077	-0.00754	-0.865	-0.0304	-0.0792	0.362	-0.00195	-0.879	-0.0304	0.0445
	(1.894)	(0.094)	(2.191)	(0.084)	(1.973)	(0.0971)	(2.236)	(0.0867)	(1.998)	(1.900)	(0.0988)	(2.227)	(1.991)	
Years of education (highest educated in HH)	-1.187	-0.002	-1.287	-0.015	-1.2233	0.00525	-1.289	-0.0091	-1.223	-1.181	0.00648	-1.293	-0.0079	-1.209
	(1.013)	(0.033)	(0.996)	(0.036)	(1.003)	(0.0336)	(1.002)	(0.0371)	(1.007)	(0.996)	(0.0340)	(0.977)	(0.035)	(0.985)
Square of years of education (highest educated in HH)	0.0492	0.0002	0.0544	0.0008	0.051	-5.13e-05	0.0546	0.0006	0.0511	0.0488	-0.000123	0.0548	0.0006	0.0503
	(0.0510)	(0.001)	(0.049)	(0.001)	(0.05)	(0.00141)	(0.0496)	(0.0016)	(0.0504)	(0.0500)	(0.0015)	(0.0482)	(0.0015)	(0.0492)
Economic variables														
Main occupation	6.217***	0.168**	5.73**	0.155	6.042**	0.117	5.724**	0.1069	6.041**	6.197**	0.113	5.729**	0.1186	6.077**
	(2.289)	(0.077)	(2.43)	(0.094)	(2.344)	(0.0745)	(2.454)	(0.0901)	(2.364)	(2.384)	(0.0737)	(2.482)	(0.0849)	(2.422)
ln(Experience in farming)	-3.003	-0.019	-3.079	-0.008	-3.03	-0.0367	-3.080	-0.0211	-3.031	-3.163	-0.0608	-3.002	-0.0144	-3.122
	(2.730)	(0.063)	(2.628)	(0.065)	(2.681)	(0.0647)	(2.626)	(0.0649)	(2.679)	(2.648)	(0.0687)	(2.515)	(0.066)	(2.629)
Mobile phone	2.449*	0.039	2.052	0.035	2.306*	0.0470	2.047	0.0429	2.306*	2.423*	0.0429	2.056	0.0294	2.329*
	(1.342)	(0.038)	(1.278)	(0.034)	(1.323)	(0.0382)	(1.261)	(0.0347)	(1.305)	(1.329)	(0.0385)	(1.249)	(0.0358)	(1.304)

contd...

ln (Distance of transportation)	1.403 (1.402)	0.066*** (0.024)	1.067 (1.336)	0.072*** (0.021)	1.281 (1.339)	0.0647** (0.0249)	1.063 (1.302)	0.0723*** (0.0209)	1.282 (1.306)	1.340 (1.144)	0.0542** (0.0253)	1.091 (1.100)	0.0566*** (0.0198)	1.276 (1.095)
Instrumental variables														
Migrants per household member (fraction share)		0.465*** (0.127)		0.454*** (0.14)										
Proportion of migrating members in total household members in a ward						0.585 (0.570)		0.8469 (0.5995)			0.683 (0.584)		1.05* (0.6226)	
Interaction of average price in a ward and proportion of contract farmers by caste in a ward		0.019*** (0.001)		0.022*** (0.002)		0.0194*** (0.0017)		0.0222*** (0.0023)			0.0188*** (0.00187)		0.0213*** (0.0024)	
Constant	38.44*** (11.49)	-0.284 (0.298)	39.328*** (11.602)	-0.147 (0.308)	38.76*** (11.459)	-0.246 (0.316)	39.34*** (11.62)	-0.1306 (0.3298)	38.76*** (11.47)	37.86*** (10.73)	-0.348 (0.317)	39.64*** (10.67)	-0.3055 (0.3299)	38.31*** (10.50)
Observations (No.)	605	605	605	605	605	605	605	605	605	605	605	605	605	605
R-squared (Centered)	0.290		0.2741		0.2876		0.274		0.2876	0.290		0.273		0.289
Root MSE	14.195		14.35		14.21		14.35		14.21	14.20		14.37		14.22
District fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Standard IV (external instruments only)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Generated instruments		No	No	Yes	Yes	No	No	Yes	Yes		No	No	Yes	Yes
Test of heteroscedasticity (Pagan-Hall general test statistic)														
Chi-sq (17)			66.024				67.632					67.98		
P-value			0				0					0		
Over-identification test														
Hansen's J statistics			0.001		15.9		0.007		14.26			0.005		15.56
P-value			0.971		0.46		0.931		0.58			0.9458		0.55
Weak identification test														
Kleibergen-Paap rk wald F statistic			63.364		12.876		62.547		12.159			55.02		14.36

Source Authors' analysis based on field survey (2014)

Notes
1. Robust standard errors in parentheses. ***, **, and * represent significance at 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the village level. 2SLS = Two-stage least squares; NPR = Nepalese rupees; OLS = Ordinary least squares.
2. The instrumental variables used in the specifications are "migrants per household member", "interaction of average price in a ward and proportion of contract farmers by caste in a ward", and "proportion of migrating members in total household members in a ward". Following Lokshin et al. (2010), we have included the specification comprising "proportion of migrants in a ward" as an instrument in the regression model.
3. The generated instruments are based on Lewbel (2012) methodology. A total of sixteen moments were generated, pertaining to each one of the exogenous variables (independent variables).Table 9 shows outcomes of the nearest neighbour matching estimation with analytical standard errors as in Abadie and Imbens (2006) and kernel-based matching with bootstrap standard errors, respectively. The unit profit for contract farmers is significantly higher than that for noncontract farmers in the range of NPR 12.11/kg (kernel-based matching) to NPR 13.38/kg (nearest neighbour matching with number of matches =5). The marginal farmers are at par with small, medium and large landholding classes, in benefitting from contract farming. Thus, across landholding classes, the ginger cultivators benefit significantly from contract based on the simple average treatment effect on the treated (SATT).

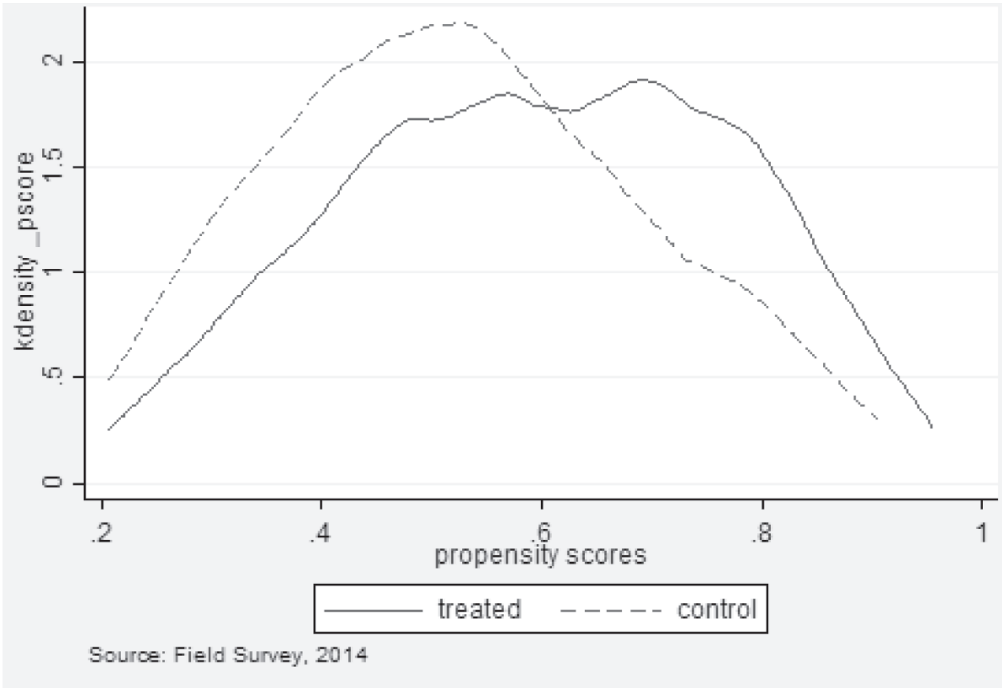


Figure 3 Common support region in PSM based on kernel density

farmers have a higher probability of participating in the CF which also relates to the incidence of migration as a relevant instrument for contracting. The educational attainment is not associated with participation in the CF. In this regard, many studies in the literature support a positive relationship (Arumugam et al., 2011; Hu, 2012; Zhu and Wang, 2007), while some other studies find a negative or insignificant relationship (Bellemare, 2012; Ito et al., 2012; Miyata et al., 2009; Wainaina et al., 2012; Wang et al., 2013). The distance of village from the road positively influences participation in the CF, showing that remoteness favours contracting. Table 9 exhibits two specifications involving clustering of standard errors at the village and ward levels.

Contract farming and profitability

Table 8 presents parameter estimates of the association of CF with unit profit from ginger cultivation in Nepal. As there is a possibility of heteroscedasticity in the data, we also followed the approach of technical instruments given in Lewbel (2012). The Breusch–Pagan test indicates the presence of heteroscedasticity. We observed parameter estimates for (i) standard IVs (i.e. external instruments only), and (ii) IVs with generated instruments and external instruments (both). The first stage in 2SLS regression is like the coefficients reported in Table 9, except for the inclusion of the instrumental variables as regressors and the method being the linear probability model. All regressions include district fixed effects, and standard errors have been clustered at the village level.

Table 8 shows that the CF of ginger in Nepal has a significant positive impact on unit profits. With the simple OLS specification, contracting is associated with a higher profit of 12.59 Nepalese rupees (NPR) per kilogram. The estimates from the IV regressions show that OLS estimates are probably downward biased. Other variables that show a significant relationship with unit profit include occupation, farm size, and access to mobile phone. Importantly, the relationship between land size and profits is positive—large farms have higher per-unit profit. An additional hectare is associated with an increase in profits by about NPR 2.4/kg. The use of standard IVs shows that participation in CF is associated with a higher profit from ginger cultivation by NPR 16.98/kg. When both generated instruments and standard IVs are used in 2SLS regression, the contract farmers earn higher profit by NPR 14.17/kg compared to the independent farmers.

Table 9 Impact of contract farming on profits: Outcomes of nearest neighbour matching and kernel-based matching

Number of matches (m)	Variable	Unit profit in ginger production (NPR/kg)		
		All farmers	Marginal farmers (<0.5ha)	Small, medium and large farmers (>0.5 ha)
m = 1	SATT	12.35***	12.72***	14.08***
		(1.715)	(2.069)	(2.090)
m = 3	SATT	13.14***	13.20***	13.24***
		(1.477)	(2.181)	(2.045)
m = 5	SATT	13.38***	13.37***	12.65***
		(1.451)	(2.205)	(1.934)
Observations		605	255	350
Bootstrap standard errors		12.11***	9.961***	13.90***
(kernel-based matching)		(1.385)	(2.262)	(1.948)
No. of observations		605	255	350

Notes Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$, m=1, 3 and 5 indicate 1, 3 and 5 neighbours, respectively. SATT = Simple average treatment effect on treated

The first specification uses the IVs: (i) number of household members migrated for employment per household; and (ii) interaction of average price in a ward and proportion of contract farmers by caste in a ward (excluding the specific household). Following Lokshin et al. (2010), we have included specification 2 comprising "proportion of migrants in a ward" as an instrument in the regression model. Specification 3 includes food safety adoption index as an added independent variable to see whether profits are influenced by the adoption of food safety measures. Te adoption of food safety measures does not seem to impact profits from the cultivation of ginger in Nepal by affecting costs and prices over and above the included factors. In addition, we assessed the impact of contract farming on output price and observed significant impacts (The results are available on request).

Impact of CF on adoption of FSM

Table 10 reports estimates of the relationship between adoption of FSM and participation in the CF using OLS and 2SLS regressions (also Lewbel 2012 approach). The Table 11 shows a significant positive impact of CF on adoption of FSM. The use of only the standard IVs indicates a better adoption of FSM by 10.5% by the contract farmers over the independent farmers. The use of generated instruments with the standard IVs exhibits that CF enhances compliance with FSMs, by about 9.2% at the farm level.

There are several ways in which CF may lead to greater compliance. It can help in transferring knowledge and skills, reduce compliance costs, and ensure a premium price to farmers. A similar relationship has been reported by Kumar et al. (2013); Narrod et al. (2009); and Roy and Thorat (2008). Further, farm-size has shown a positive and significant effect on the adoption of FSM. The large farms may be able to exploit economies of scale in compliance with FSMs.

Table 11 depicts the outcomes for FSMs based on matching. The contract farmers are significantly better adopters of FSM at the farm-level than noncontract farmers in the range of 4.1% (kernel-based matching) to 6.3% (nearest neighbour matching with number of matches =1). The benefit of CF in adoption of FSM at the farm-level is evident across farm-size classes, though it is least pronounced for marginal farmers.

Table 10 Impact of CF on adoption of food safety measures (FSM)

Dependent variable: Food Safety Adoption Index (FSI)

Variable	OLS	2SLS (Specification 1)				2SLS (Specification 2)			
		Standard IV results		IV with generated instruments and external instruments		Standard IV results		IV with generated instruments and external instruments	
		Ist stage	2nd stage	Ist stage	2nd stage	Ist stage	2nd stage	Ist stage	2nd stage
Contract farming	4.760***		10.454***		9.162***		10.24***		6.396***
	(1.626)		(2.905)		(2.794)		(2.461)		(2.204)
Socio-demographic variables									
Age of household-head	-1.414***	0.011	-1.45***	0.009	-1.441***	0.0131	-1.449***	0.0142	-1.424***
	(0.445)	(0.009)	(0.46335)	(0.011)	(0.455)	(0.00975)	(0.463)	(0.0116)	(0.448)
Square of age of household-head	0.0108***	-0.00008	0.01***	-0.00006	0.01***	-8.12e-05	0.0110***	0.0001	0.0109***
	(0.00342)	(0.00008)	(0.003)	(0.0001)	(0.003)	(8.74e-05)	(0.00352)	(0.0001)	(0.00343)
ln(Household size)	-1.605	-0.049	-1.669	-0.09	-1.654	0.0243	-1.667	0.0021	-1.623
	(2.008)	(0.06)	(2.023)	(0.055)	(2.017)	(0.0522)	(2.022)	(0.0449)	(2.008)
Gender	1.125	-0.115***	1.988	-0.126***	1.792	-0.114***	1.956	-0.1252***	1.373
	(1.826)	(0.041)	(1.963)	(0.038)	(1.924)	(0.0431)	(1.919)	(0.0371)	(1.852)
ln(Operational land)	3.013**	0.004	3.059**	0.011	3.049**	0.00166	3.058**	0.0119	3.027**
	(1.354)	(0.032)	(1.441)	(0.032)	(1.416)	(0.0328)	(1.436)	(0.029)	(1.372)
Caste									
General	-1.380	-0.029	-2.136	-0.06	-1.964	0.00114	-2.108	0.0014	-1.598
	(2.770)	(0.095)	(3.104)	(0.078)	(2.971)	(0.0962)	(3.099)	(0.0733)	(2.814)
Tribal	-0.388	-0.01	-1.947	-0.034	-1.593	0.0177	-1.888	-0.017	-0.836
	(2.369)	(0.094)	(2.728)	(0.084)	(2.528)	(0.0966)	(2.755)	(0.0761)	(2.425)
Years of education	-0.426	0.003	-0.555	-0.011	-0.525	0.0135	-0.551	0.0168	-0.463
(highest educated in HH)	(0.858)	(0.034)	(0.933)	(0.037)	(0.921)	(0.0326)	(0.930)	(0.0335)	(0.878)
Square of years of education	0.0252	-0.00001	0.032	0.0007	0.03	-0.000420	0.0318	-0.0003	0.0272
(highest educated in HH)	(0.0445)	(0.001)	(0.046)	(0.001)	(0.046)	(0.00145)	(0.0469)	(0.0014)	(0.0451)
Economic variables									
Main occupation	1.335	0.158**	0.703	0.154	0.847	0.134*	0.728	0.1089	1.154
	(3.576)	(0.076)	(3.664)	(0.093)	(3.68)	(0.0679)	(3.707)	(0.0814)	(3.647)
ln(Experience in farming)	10.32**	-0.026	10.219**	-0.011	10.241**	-0.0654	10.22**	-0.0729	10.29**
	(4.670)	(0.064)	(4.838)	(0.066)	(4.808)	(0.0627)	(4.832)	(0.0638)	(4.720)
Excess to mobile phone	1.700	0.042	1.186	0.037	1.302	0.0604	1.206	0.0452	1.553
	(1.622)	(0.037)	(1.742)	(0.034)	(1.712)	(0.0376)	(1.719)	(0.0324)	(1.677)
ln(Distance of transportation)	4.049***	0.065**	3.614***	0.071***	3.712***	0.0603**	3.631***	0.0676***	3.924***
	(1.222)	(0.024)	(1.212)	(0.021)	(1.191)	(0.0244)	(1.199)	(0.0196)	(1.195)

Contd...

Instrumental variables									
Number of household members migrated		0.058***		0.065***					
		(0.019)		(0.019)					
Proportion of migrating members in total household members in a VDC						3.726***		8.7715***	
						(0.704)		(2.4218)	
Interaction of average price in a ward and proportion of contract farmers by caste in a ward		0.019***		0.023***		0.0170***		0.0183***	
		(0.001)		(0.002)		(0.0021)		(0.0023)	
Constant	37.59**	-0.213	38.744**	-0.058	38.483**	-0.685**	38.70**	-1.2244***	37.92**
	(15.20)	(0.305)	(16.12)	(0.316)	(15.957)	(0.328)	(16.13)	(0.3956)	(15.49)
Observations (No.)	605	605	605	605	605	605	605	605	605
R-squared (Centered)	0.246	0.347	0.2191	0.389	0.2297		0.221		0.243
Root MSE	14.541	0.4093	14.79	0.4011	14.69		14.77		14.56
District Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Standard IV (external instruments only)		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Generated instruments		No	No	Yes	Yes	No	No	Yes	Yes
Test of heteroscedasticity (Pagan-Hall general test statistic)									
Chi-sq (17)			69.816				69.258		
P-value			0				0		
Over-identification test									
Hansen's J statistics			0.12		19.3		0.000		18.288
P-value			0.729		0.254		0.9906		0.3073
Weak identification test									
Kleibergen-Paap rk Wald F statistic			63.834		12.619		121.61		12.52

Source Authors' analysis based on field survey (2014).

Notes
1. Standard errors in parentheses. ***, ** and * represent significance at 1%, 5% and 10% levels, respectively. Standard errors are clustered at the village level. 2SLS = Two-stage Least Squares; NPR = Nepalese rupees; OLS = Ordinary Least Squares
2. The instrumental variables used in the specifications are "number of household members migrated", "interaction of average price in a ward and proportion of contract farmers by caste in a ward", and "proportion of migrating members in total household members in a VDC". Following Lokshin et al. (2010), we have included the specification comprising "proportion of migrants in a VDC" as an instrument in the regression model.
3. The generated instruments are based on Lewbel (2012) methodology. A total of sixteen moments were generated, pertaining to each one of the exogenous variables (independent variables).

Table 11 Impact of contract farming on adoption of FSM at farm-level: Estimates of the nearest neighbour matching and kernel-based matching

Number of matches (m)	Variable	Food Safety Adoption Index (FSI)		
		All farmers	Marginal farmers (< 0.5 ha)	Small, medium and large farmers (> 0.5 ha)
m = 1	SATT	6.335***	4.215*	7.396***
		(1.720)	(2.276)	(2.177)
m = 3	SATT	5.859***	4.574**	6.840***
		(1.451)	(2.141)	(2.053)
m = 5	SATT	6.042***	5.200**	6.942***
		(1.467)	(2.170)	(2.011)
Observations		605	255	350
Bootstrap standard errors		4.121***	2.477	4.811**
(kernel-based matching)		(1.378)	(2.101)	(1.884)
Observations		605	255	350

Notes Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1, m=1, 3 and 5 indicating 1, 3 and 5 neighbours respectively. SATT = Simple average treatment effect on treated

Conclusions

One of the strongest criticisms of CF in the developing countries stems from the perception that small farmers will be exploited by the "big" integrators, especially when they have limited options, as is the case in remote areas. In fact, there has been an intense debate in the literature and in policy circles in countries like Nepal, and some researchers and policymakers perceive CF as being close to bonded labour, while others perceive it as a way of promoting agricultural commercialization. This paper has looked at the issue in a specific context in which the farmers are in the remote areas of Nepal. Using the 2014 survey from ginger-producing households in the hill districts of Nepal, this study has shown the impact of their participation in CF in ginger cultivation on profits and on the adoption of FSMs at the farm level.

Our results show that in terms of land size, there is no systematic bias against the small farmers on participation in the CF. Other attributes such as gender of the head of household, outmigration, low caste, transportation costs, and access to mobile phone are important determinants of participation in the CF, and the results broadly point towards negative selection. Conditional on participation, the contract farmers earn significantly higher net profits than noncontract farmers. The source of higher profit comes mainly from higher output prices, though cost containment is an important part of the story. Further, CF has a significant positive impact on the adoption of FSMs at the farm level.

These findings have several important policy implications.

The study has some limitations. First is that the data is cross-sectional and hence, the findings are short-term in nature. Second, we do not have information on farmers' characteristics at the time of joining the contract. Third, it is not an experimental data and we barely have information on side-selling.

Our study suggests that CF can increase farmer's income substantially and bring improvement in compliance with FSMs even in the remote areas. In CF, the choice of farmers by the integrators, the value distribution, and the location effect interact in complex ways, and it is hard to guess the net effects. Just as transaction costs and possible monopsony power of the buyers hamper contracting in the remote areas, agro-ecology or limited side selling opportunities work in favour of linking with farmers in these areas. The case of CF in ginger cultivation shows that in the net, the positives happen to outweigh the negative countervailing forces.

The imperfect credit markets, lump-sum transportation costs for small amounts of produce, imperfect information about market prices, lack of technological knowledge, inability of small and marginal farmers to absorb less risks are only a few of the problems facing the farmers in the remote areas. In this paper, we look at a specific case to see how some of these problems have been solved through agreements among farmers and between farmers and integrators.

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Received 22 February 2024 Accepted 7 June 2024

Agricultural Economics Research Review 2024, 37 (1), 79-91
DOI: 10.5958/0974-0279.2024.00002.1

Vulnerability of the Indian cashew market to global price shocks

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Abstract The Indian cashew sector is grappling with a severe crisis as numerous processing industries have closed down due to losses and heightened global competition. In this context, we assess the vulnerability of the sector to global price shocks by examining the direction and dynamics of price transmission among import price, domestic price and export price of cashew in India, based on 15 years of data, employing the vector autoregressive model. Results indicate that the import price had positive and immediate effects on both the domestic price and export price of Indian cashew and the relationship was unidirectional, revealing the vulnerability of Indian cashew markets to global price fluctuations.

Keywords Granger causality test, impulse response analysis, raw cashew nut, vector autoregressive model

JEL codes Q11, Q17, Q18

The Indian cashew sector is witnessing rapid changes. India was the global leader in cashew cultivation before it was overtaken by Ivory Coast in 2019 with respect to production and in 2010 in terms of area under cashew cultivation (FAOSTAT, 2022). Presently, it ranks second in both area (15.71%) and production (18.48%) of cashew nut. India was the pioneer in establishing cashew processing as an industry (CEPCI, 2021). It was the first country to initiate the export of cashew kernels to the world market, starting with the US (Tessmann, 2021). India dominated the global export of cashew kernels due to their superior quality and popularity.

Further, India has been importing large quantities of raw cashew nut (RCN) to meet the requirements of the domestic processing industry: almost 50% of the Indian demand is met through the import of RCN, especially from African countries. But Vietnam surpassed India both in import (since 2016) and export (since 2006) (FAOSTAT, 2022). Presently, in global RCN import and cashew kernel export, India accounted for 41% and 8%, respectively, while Vietnam accounted for 57% and 70%, respectively (FAOSTAT, 2022). The cashew sector, besides earning a substantial foreign exchange (US $424.5 million), provides employment opportunities to about 1.5 million people involved in the agriculture and processing sectors, which majorly include women, tribal people, and people from the underdeveloped and weaker sections of the society (DCCD, 2021).

However, the cashew processing industries are now facing a crisis. In Kollam, a city in Kerala which is popularly known as India's cashew capital, it is reported that around 90% of the processing units have closed down (Parvathy, 2018). Besides this, many other states of India have also witnessed similar situations (Patil, 2016; D'Silva and Bhat, 2021). Some of the reported reasons for this crisis are increased competition in the global market, trade agreements and the growth of the processing industry in African countries where both labour and RCN are cheaper (Many, 2019). This crisis would adversely affect the livelihood security of the various stakeholders involved in this sector.

Considering these issues, we have tried to assess the vulnerability and sustainability of the cashew industry to global market price fluctuations. We examined seasonality in import and export from India and carried out the growth and instability analysis of the Indian and global cashew sectors. We studied the nature and direction of the relationship between the import price (IP), the domestic price (DP) and the export price (EP) of cashew in India.

Materials and methods

Variables and data sources

To study the inter-relationships, the data was collected and compiled from the monthly time series on IP, DP and EP of cashew in India from multiple sources for the last 15 years (January 2007 to April 2022—a total of 184 months). The RCN occupied the largest share in the total cashew import by India. During 2021–22, the share of RCN (HSN Code 8013100) was 99.5% of the total cashew import by India. Hence, the unit price of imported RCN was used as the IP of cashew. However, the scenario was different in cashew export from India. Cashew kernels (HSN Code 8013220) contributed a major share to the total cashew export (82% during 2021–22) and therefore we considered the unit price of exported cashew kernels as the EP of cashew.

Accordingly, we collected data on the quantity and value of monthly import of RCN and export of cashew kernels from the Export Import Data Bank, Ministry of Commerce and Industry, Government of India. For DPs of cashew, we collected the monthly prices of RCN from major cashew-producing states (Andhra Pradesh, Goa, Karnataka, Kerala, Odisha and Tamil Nadu) from the Directorate of Marketing and Inspection, Ministry of Agriculture and Farmers Welfare, Government of India, and arrived at the monthly average RCN prices for India.

To understand the trends in the cashew sector, the data on trade and global and domestic production was collected from the Food and Agriculture Organization of the United Nations and the Ministry of Agriculture and Farmers Welfare, Government of India, from 2007–08 to 2021–22. We also collected data on global and domestic cashew consumption for the study period from various issues of statistical yearbooks released by the International Nut and Dried Fruit Council Foundation.

Analytical framework and empirical issues

For studying the dynamic behaviour of time-series data, the vector autoregressive (VAR) model is a powerful tool (Lashitew, 2017; Claveria and Soriæ, 2022) and it has been used to analyse transmission and causation in agricultural commodities markets (Wu and Zhou, 2015; McFarlane, 2016). The advantage of the VAR model is that it allows all the model variables to be endogenous and it models the dynamic relationship between a variable with its own lagged values and also with that of other model variables. Hence, to understand the direction and dynamics of price transmission in the Indian cashew sector, we employed the VAR model using R Package *vars* (Pfaff and Stigler, 2021).

In the VAR model, we considered three endogenous variables ($Y_{1,t}$ is IP, $Y_{2,t}$ is EP and $Y_{3,t}$ is DP) of the VAR(p) process as shown below:

$$Y_{1,t} = C_1 + \sum_{i=1}^{p} \varphi_{1,i} y_{1,t-i} + \sum_{i=1}^{p} \theta_{1,i} y_{2,t-i} + \sum_{i=1}^{p} \gamma_{1,i} y_{3,t-i} + \sum_{j=1}^{m} \delta_{1,j} s_j + \mu_{1,t}$$

$$Y_{2,t} = C_2 + \sum_{i=1}^{p} \varphi_{1,i} y_{1,t-i} + \sum_{i=1}^{p} \theta_{1,i} y_{2,t-i} + \sum_{i=1}^{p} \gamma_{1,i} y_{3,t-i} + \sum_{j=1}^{m} \delta_{2,j} s_j + \mu_{2,t}$$

$$Y_{3,t} = C_3 + \sum_{i=1}^{p} \varphi_{1,i} y_{1,t-i} + \sum_{i=1}^{p} \theta_{1,i} y_{2,t-i} + \sum_{i=1}^{p} \gamma_{1,i} y_{3,t-i} + \sum_{j=1}^{m} \delta_{3,j} s_j + \mu_{3,t} \qquad \ldots(1)$$

In equation (1), C denotes constant, s refers to the seasonal dummy and μ is the error term.

For reliable estimates, the stationarity of the time series is important. Hence, to test the stationarity, we used the Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. In the ADF test, the null hypothesis is that the variable has a unit root (non-stationary) and in the KPSS test, the null hypothesis is that the series has no unit root (Romero-Avila, 2009).

The results of the VAR model can be interpreted through summary measures such as causality tests and impulse response functions (IRF). Hence, to understand the dynamic relationships between variables, we performed two causality tests: F-type Granger causality test and Wald-type instantaneous causality test. A variable x is Granger causal to y if future values of y can be better predicted when the current and past values of x are used. x is instantaneously Granger causal to y if the future value of y can be better predicted when the future values of x are used in addition to the current and past values of x (Kirchgassner et al., 2013). For both Granger- and instantaneous causality tests, the vector of endogenous variables y_t is split into y_{1t} and y_{2t} with dimensions $(K_1 \times 1)$ and $(K_2 \times 1)$ with $K = K_1 + K_2$. The VAR(p) can be rewritten as:

$$[y_{1t}, y_{2t}] = \sum_{i=1}^{p} [\alpha'_{11,i}, \alpha'_{12,i} | \alpha'_{21,i}, \alpha'_{22,i}][y_{1,t-i}, y_{2,t-i}] + CD_t + [u_{1t}, u_{2t}] \quad (2)$$

The null hypothesis for the Granger causality test is that the subvector y_{1t} does not Granger-cause y_{2t}, which is the same as for $\alpha_{21,i} = 0$ for $i = 1,2 ..., p$. The test statistic is distributed as $F(pK_1K_2, KT - n^*)$, where n^* is equal to the total number of parameters in the above VAR(p).

For the instantaneous causality test, the null hypothesis is $C\sigma = 0$ where C is a $(N \times K(K+1)/2$ matrix of rank N, selecting the relevant co-variances of u_{1t} and u_{2t}. The Wald statistic is:

$$\lambda_W = T\tilde{\sigma}'C'[2CD_K^{+}(\tilde{\Sigma}_u \otimes \tilde{\Sigma}_u)D_K^{+}C']^{-1}C\tilde{\sigma} \quad (3)$$

where the duplication matrix D_K with dimension $(K^2 \times \frac{1}{2}K(K+1)$ is defined such that for any symmetric $(K \times K)$ matrix A, $vec(A) = D_K\, vech(A)$ holds. The test statistic λ_W is asymptotically distributed as $\chi^2(N)$.

The impulse response analysis helps to understand the impact of the positive shock of impulse variables on the future behaviour of response variables and helps in understanding the price transmission in agricultural commodities (Harvey et al., 2017; Bergmann et al., 2017). We used the impulse response analysis to investigate the relationship between variables in a higher dimensional system. The standard percentile interval for this purpose is defined as:

$$CI_s = [s^*_{\alpha/2}, s^*_{1-\alpha/2}] \quad (4)$$

where $s^*_{\alpha/2}$ and $s^*_{1-\alpha/2}$ are the $\alpha/2$ and $1-\alpha/2$ quantiles of the bootstrap distribution.

The flowchart of the overall analysis carried out on the price series is depicted in Figure 1. Before proceeding with the VAR analysis, we subjected three price series (IP, DP of RCN and EP of cashew kernels) to stationarity tests. We determined the optimal lag length for VAR by minimizing the information criteria, after which, we specified and estimated the VAR model and performed diagnostic tests. Later, with the help of Granger-causality analysis and impulse response analysis, we interpreted the results from the VAR model.

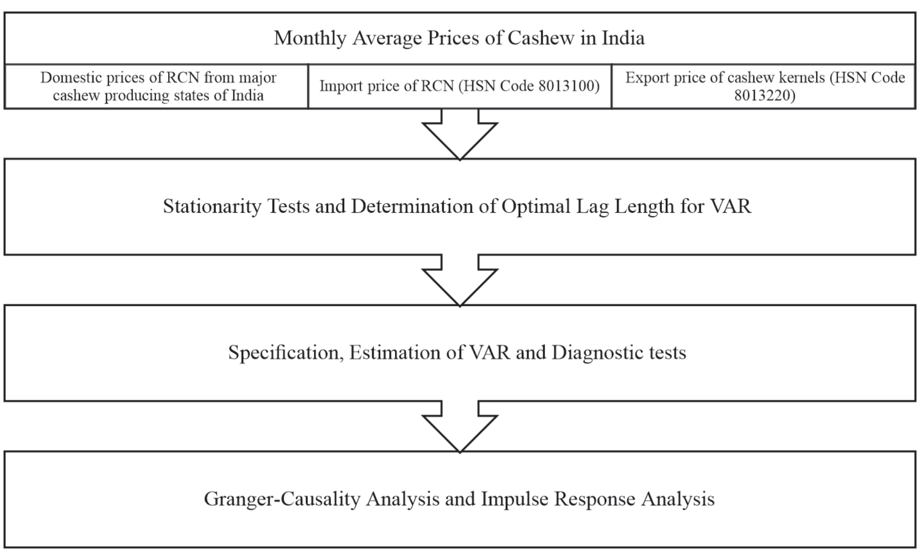

Figure 1 Flowchart of the VAR analysis
Source Diagrammatic representation of analysis by authors
Note RCN = raw cashew nut

In addition, we used Kruskal-Wallis and Welch tests for seasonality to detect the presence of seasonality in monthly import and export of cashew from India using R package *seastests* (Ollech and Webel, 2020). We derived seasonal indices for import and export quantities using multiplicative decomposition. To understand the growth dynamics, exponential growth rates and Cuddy-Della Valle Instability indices were estimated for yearly data on domestic production, import of RCN and export of cashew kernels from India.

Results and discussion

Trends in global and Indian cashew sectors

Introduced by Portuguese traders as a tree for soil erosion control in India and Africa, presently the cashew nut is grown commercially in around 46 countries across Africa, Asia and Latin America. Among these, 18 are the least developed countries which majorly export RCN to India and Vietnam for processing (UNCTAD, 2021). Indian trade policy allows duty-free import of RCN from the least developed countries and this is also one of the reasons for the major share of import by India originating from these countries. During 2021–22, India imported RCN from Benin (21%), Ghana (13%), Guinea Bissau (12%) and Ivory Coast (11%) (FAOSTAT, 2022).

Due to increasing demand, the global cashew sector is expanding. Global production, import, export and consumption—all registered significant growth rates during the study period (Supplementary Table 1). Considering a recovery ratio of 30%, we estimated the domestic consumption of cashew kernels in India. In India as well, production (1.02%), import (1.78%) and consumption (3.27%) grew significantly over the years. However, export from India has declined sharply (–6.24%). Presently, Ivory Coast and Tanzania are the leading exporters of RCN both in value and quantity terms, while India ranks 13th in export quantity and 14th in export value of RCN (FAOSTAT, 2022).

The import of RCN, both in India and globally, exhibited higher instability indices compared to that of production. Previous studies indicated positive growth rates in the production of cashew nut from both the eastern and western regions of India (Kandeeban et al., 2020). Using the trade balance index analysis, it was reported that India was losing its comparative advantage for cashew kernels (Saxena et al., 2022). Consequently, the export performance of cashew compared to other crop groups such as cereals, pulses, oilseed, tea, and coffee was found not satisfactory (Bhatia et al., 2021; Kumar, 2022). In the post-COVID period, there is an increasing demand for a healthy diet and plant-based sources of protein and hence, the consumption of cashew in both domestic and global markets is likely to grow.

Seasonality in the Indian cashew trade

We notice the presence of seasonality in RCN import by India (Figure 2). The results of Kruskal-Wallis and Welch tests also indicate the presence of significant seasonal movements. Seasonal indices reveal that the months of September (180%), October (194%) and November (167%) registered higher import and while February (53%), March (51%) and April (55%) recorded lower import (Supplementary Figure 1). However, in the case of the export of cashew kernels, there was no visible seasonal effect and both the Kruskal-Wallis and Welch tests failed to detect seasonal movements. The peak harvesting season in India is from March to May. But the cashew processing industries need year-round RCN availability for viable operations. As the harvesting season in Africa is different from India (e.g., in Guinea Bissau, it extends till August), India imports a substantial quantity of RCN during these months, which helps to run the domestic processing industries.

Descriptive statistics of VAR variables

Descriptive statistics of the three time series variables used in the VAR model viz., monthly IP and DP of RCN and EP of cashew kernels, are presented in Table 1 and Figure 3. It is observed that both the import and domestic prices of RCN moved together while the EP of cashew kernel, which is a finished product, was on an average five times higher. All these price series peaked during 2017. An increasing demand coupled with an 8% decline in global production in 2016, mainly in Vietnam, led to price spikes. Subsequently, due to an oversupply in international markets, prices dropped sharply (UNCTAD, 2021). The coefficient of variation was higher in import (31%) and domestic prices (29%), while it was lower in the finished exported product (23%).

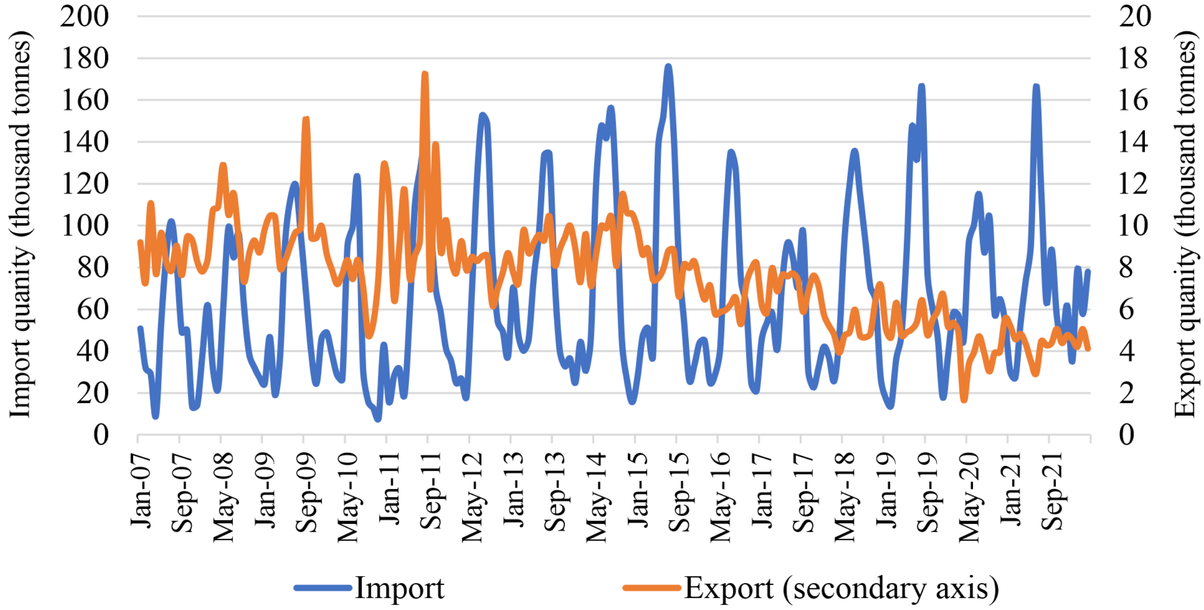

Figure 2 Monthly RCN import and export of cashew kernels from India (Jan 2007–April 2022)
Source Export Import Data Bank, Ministry of Commerce and Industry, Government of India
Note For RCN import: Kruskall-Wallis test statistic for seasonality = 33.25 (p value <0.001); Welch test statistic for seasonality = 122.80 (p value <0.001). For cashew kernels export: Kruskall-Wallis test statistic for seasonality = 0.98 (p-value = 0.4747); Welch test statistic for seasonality = 13.88 (p-value = 0.2395).

Table 1 Descriptive statistics of the monthly import price, domestic price of raw cashew nut and export price of cashew kernels (January 2007–April 2022)

(per quintal)

Descriptive statistics	Import price (US $)	Domestic price (US $)	Export price (US $)
Count	184	184	184
Mean	130.86	131.18	751.49
	(7,979.73)	(7,971.7)	(45,819.91)
Minimum	56.82	65.75	221.43
	(2,319.43)	(2,681.31)	(10,725.74)
Maximum	180.21	170.36	889.04
	(12,908.09)	(12,442.23)	(61,554.97)
Range	56.82	65.75	221.43
	(2,319.43)	(2,681.31)	(10,725.74)
Standard error	2.97	2.78	12.95
	(245.38)	(234.22)	(1,226.65)
Median	126.39	127.18	780.19
	(7,821.38)	(7,442.52)	(46,490.96)
Standard deviation	40.28	37.71	175.63
	(3,328.50)	(3,177.14)	(16,639.07)
Coefficient of variation (%)	30.78	28.75	23.37
	(41.71)	(39.86)	(36.31)

Source Ministry of Commerce and Industry, Government of India and Directorate of Marketing and Inspection, Ministry of Agriculture and Farmers Welfare, Government of India
Note Values in parenthesis are expressed in Indian Rupee (INR)

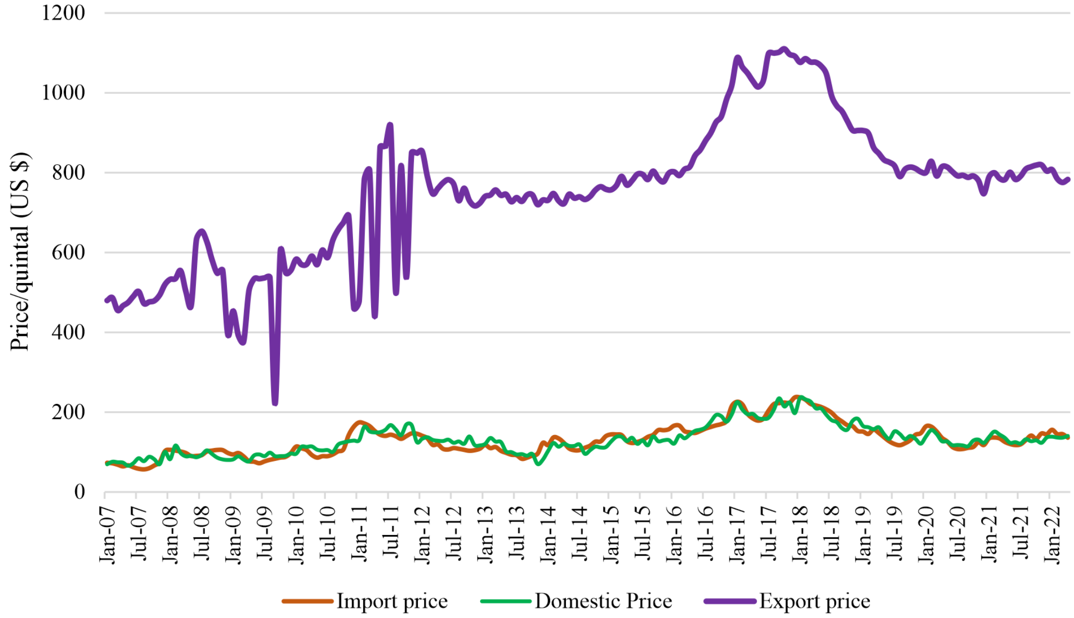

Figure 3 Monthly import price, domestic price of RCN and export price of cashew kernels from India (January 2007–April 2022)

Source Export Import Data Bank, Ministry of Commerce and Industry, Government of India

Unit root tests

The stationarity of time series is important for obtaining reliable estimates. Hence, to test the stationarity, we used ADF and KPSS unit root tests. The results of the unit root test at the level (before differencing) and the first difference of the variables are given in Table 2. Both ADF and KPSS tests indicate that the variables were not stationary at the level; however, they were stationary at the first difference. Hence, we differenced all three series before fitting the VAR model.

Selection of lag length

While selecting the appropriate lag length for the VAR model, the general rule is to minimize the information criteria. For this purpose, we used four information criteria viz., Akaike information criterion (AIC), Hannan-Quinn information criterion (HQ), Schwarz information criterion (SC) and Final prediction error (FPE). In Table 3, the results are presented and the minimum values for each of these information criteria are highlighted in bold. Most of the information criteria (AIC, HQ and FPE) reveal that a lag of three was optimal except SC, which suggested that a lag of one was appropriate. Just to cross-check, we fitted different VAR models using a lag of one, two and three, and we also found that the model with a lag of three was performing better. Hence, a lag of three was used for further VAR modelling.

Table 2 ADF and KPSS unit root tests

Variables	Level		First difference	
	ADF	KPSS	ADF	KPSS
Import price	-1.861	2.803***	-6.585***	0.066
Domestic price	-1.618	2.879***	-6.102***	0.093
Export price	-0.780	3.379***	-7.161***	0.100

Source Authors' estimates

Note *** significant at 1%

Null hypothesis of ADF unit root test: Variable has a unit root; Null Hypothesis of KPSS test: Variable has no unit root.

VAR estimation

With the lag order of three and monthly seasonal dummy variables (SD1 to SD11), on the first differenced variables of IP, EP and DP, the VAR was estimated using the R package *vars*. The results are presented in Table 4. The overall model was significant as indicated by all the three F statistics (4.862 for IP, 4.840 for EP and 3.411 for DP; all significant at 1% level). The multiple R^2 values were 0.38 for IP and EP each, and it was 0.30 for DP. Further, we performed diagnostic tests. The Portmanteau test (asymptotic) revealed that the residuals from the VAR model were

Table 3 Selection of appropriate lag length using information criteria

Information Criteria	Lag					
	1	2	3	4	5	6
AIC(n)	4.20E+01	4.20E+01	4.18E+01*	4.19E+01	4.19E+01	4.20E+01
HQ(n)	4.23E+01	4.24E+01	4.23E+01*	4.25E+01	4.26E+01	4.27E+01
SC(n)	4.28E+01*	4.30E+01	4.30E+01	4.33E+01	4.35E+01	4.37E+01
FPE(n)	1.75E+18	1.72E+18	1.50E+18*	1.61E+18	1.66E+18	1.75E+18

Source Authors' estimates
Note *indicates lag order selected by the criterion. AIC: Akaike information criterion; HQ: Hannan-Quinn information criterion; SC: Schwarz information criterion; FPE: Final prediction error.

Table 4 Results of VAR model

Variables	Import price (IP)	Export price (EP)	Domestic price (DP)
IP_{t-1}	0.130	0.536	0.369***
	(0.079)	(0.586)	(0.109)
EP_{t-1}	0.006	-0.663***	0.007
	(0.010)	(0.076)	(0.014)
DP_{t-1}	0.001	0.666	-0.391***
	(0.057)	(0.425)	(0.079)
IP_{t-2}	0.202**	0.635	0.122
	(0.081)	(0.6)	(0.112)
EP_{t-2}	-0.005	-0.409***	-0.007
	(0.012)	(0.087)	(0.016)
DP_{t-2}	0.001	0.576	-0.21**
	(0.061)	(0.453)	(0.084)
IP_{t-3}	-0.246***	0.877	0.106
	(0.081)	(0.605)	(0.113)
EP_{t-3}	-0.002	-0.313***	-0.026
	(0.010)	(0.076)	(0.014)
DP_{t-3}	0.098*	0.532	-0.128
	(0.057)	(0.422)	(0.079)
Constant	35.560	357.093	49.67
	(34.840)	(259.34)	(48.38)
SD1	-282.300	275.669	405.8*
	(173.600)	(1292.069)	(241)
SD2	-415.300**	-700.326	-282.9
	(188.100)	(1400.341)	(261.2)
SD3	-607.600***	-318.255	-150.9
	(190.600)	(1419)	(264.7)
SD4	-401.200**	2495.428*	-95.79
	(192.900)	(1436.112)	(267.9)
SD5	-214.000	3330.695**	-244.6
	(195.300)	(1453.537)	(271.2)
SD6	-162.600	2680.901*	-37.32
	(190.100)	(1415.086)	(264)
SD7	-28.100	741.67	8.969
	(181.800)	(1353.719)	(252.6)
SD8	1.887	695.401	34.8
	(174.700)	(1300.271)	(242.6)
SD9	-69.770	258.997	-29.78
	(173.500)	(1291.748)	(241)
SD10	229.700	1012.11	-316.2
	(173.300)	(1290.347)	(240.7)
SD11	246.700	-186.516	-360.7
	(170.800)	(1271.197)	(237.2)
Residual standard error	458.40	3413.00	636.70
Multiple R^2	0.3795	0.3784	0.3002
Adjusted R^2	0.3015	0.3002	0.2122
F-statistic	4.862***	4.840***	3.411***

Contd...

Source Authors' estimates
Note *significant at 10%, ** at 5% and *** at 1%; SD = Seasonal Dummy; Portmanteau Test (asymptotic): Chi-squared = 201.09, df = 189, p-value = 0.2601; ARCH (multivariate) Test: Chi-squared = 857.85, df = 864, p-value = 0.5526; Stability test – fulfilled.

white noises (χ^2 value 201.09^{NS}). From the autoregressive conditionally heteroscedastic (ARCH) test (multivariate), it can be inferred that the ARCH effect was not present (χ^2 value 857.85^{NS}). The results of the structural stability test of the VAR model using the Ordinary Least Square Cumulative Sum (OLS-CUSUM) fluctuation process indicates that the stability requirement of the VAR was fulfilled (Supplementary Figure 2).

As a p-lag VAR model contains many parameters and the VAR system treats all the variables as endogenous within the system, interpreting the individual coefficients is not possible. Hence, different summary measures (Granger causality test and impulse response analysis) were used to understand and interpret the dynamics among these variables.

Granger causality test

The results of the Granger causality test are presented in Table 5. They indicate that the IP Granger caused

Table 5 Results of Granger causality test

Sr. No.	Cause	Null hypothesis (H_0)	F-test	p-value
1	IP	IP do not Granger-cause EP, DP	3.191***	0.004
		No instantaneous causality between: IP and EP, DP	11.199***	0.004
2	DP	DP do not Granger-cause IP EP	1.133^{NS}	0.342
		No instantaneous causality between: DP and IP, EP	7.670**	0.022
3	EP	EP do not Granger-cause IP DP	0.903^{NS}	0.492
		No instantaneous causality between: EP and IP, DP	5.635*	0.060

Source Authors' estimates
Note * significant at 10%, ** at 5% and *** at 1%, NS – Not significant at 10%.
IP: import price; EP: export price and DP: domestic price

EP and DP, as depicted by the significant F statistic (3.191***). However, the DP did not Granger cause IP and EP, with a non-significant F statistic (1.133^{NS}). Results also indicate that the EP did not Granger cause IP and DP (F statistic 0.903^{NS}).

Further, it can also be observed that instantaneous causality relationships existed in the system, but were significant at different levels. The null hypothesis of no instantaneous causality between IP and EP, DP was rejected at 1 per cent level (F statistic 11.199***). The null hypothesis of no instantaneous causality between DP and IP, EP was rejected at 5 per cent level (F statistic 7.670**). The null hypothesis of no instantaneous causality between EP and IP, DP was rejected at 10 per cent level of significance (F statistic 5.635*). All the instantaneous causality results were significant within the system. This indicates the presence of interlinkages within the system. However, the Granger causality tests reveal the unidirectional price transmission from import prices to domestic and export prices.

Impulse response analysis

The dynamic effect of one variable on others over a period of time can be visualized using an impulse response analysis. The results of the impulse response analysis are depicted in Figure 4. They indicate the effect of one standard deviation positive shock in the impulse variable on the response variable over a period of time. It can be observed from the top-left box of Figure 4 that a shock in IP had a positive and significant effect on the DP for the initial two months, as indicated by the confidence intervals. Similarly, the shock in IPs significantly affected the EPs. As indicated by the top-right box of Figure 4, the effect of a shock in IP was positive and significant on the EP for the initial month. In both these cases, the effects of shock in IPs were immediate, mostly transmitted during the same month. However, the effect of shock in EP on DP was delayed by a period of five months, indicating a lag. Effects of the other shocks in the system were not statistically significant as the confidence intervals contain zero.

We infer that the shocks in IP were transmitted to domestic and export prices immediately, within two months. It was quicker compared to the transmission from EP to DP, which took five months. Both the DP and EP in India were significantly, immediately and unidirectionally impacted by changes in IPs. This indicates the vulnerability of the Indian cashew market to global price shocks. The declining importance of the Indian cashew market in global trade is likely to enhance the vulnerability in the coming years.

Conclusion and policy implications

In the present global cashew market scenario, India's role has been diminishing over the years. Increasing global competition, especially from booming markets such as Vietnam, African countries, and domestic factors like increasing wages and processing costs have affected the profitability of the Indian cashew industry. To assess the vulnerability of the Indian cashew market to global price shocks, we performed a VAR analysis on monthly IPs, DPs of RCN and EPs of cashew kernels from India. Results indicated that the IPs significantly and unidirectionally affected both DPs and EPs of cashew in India with immediate price transmissions. This reveals the vulnerability of Indian cashew markets to global price shocks. As the countries from which India is currently importing, such as Benin, are planning

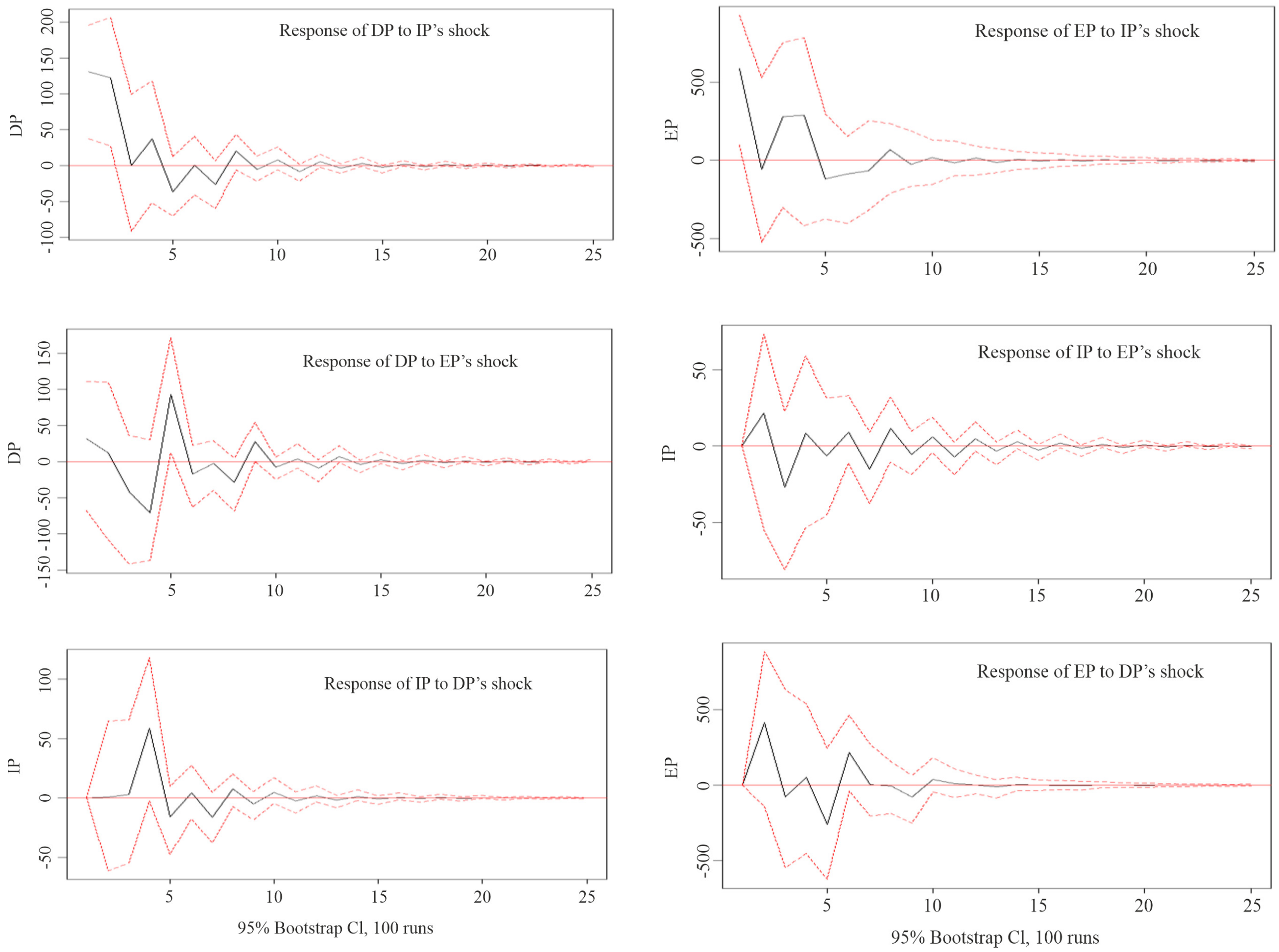

Figure 4 Impulse response analysis of import price, domestic price of RCN and export price of cashew kernels from India

Source Authors' estimates

to impose export restrictions/bans on RCN, the vulnerability is likely to increase.

However, reducing the dependence on import is difficult as: i) around 50% of the requirement of domestic cashew industries is met from RCN import; ii) RCN is imported mainly during the offseason (September–November) to keep the domestic processing industries running; and iii) increasing domestic consumption of cashew in India. Hence, a two-fold strategy can be adopted. First, the imported RCN can be used to fulfil the demands of price-sensitive consumers. Second, the domestically produced RCN can be used to target premium sectors of both domestic and global markets, utilising its superior quality and the trust built up over the years. This is expected to fetch higher prices for domestic RCN which would help in enhancing production, bringing additional area and improving productivity through the rejuvenation of senile cashew plantations and the adoption of high-yielding varieties in India. Such measures would make the Indian cashew sector more resilient to face the upcoming challenges and tap into the growing domestic and global demand, especially in the post-COVID era when people are prioritising plant-based sources of protein.

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Received 7 December 2023 Accepted 4 March 2024

Supplementary Table 1 Trends in global and Indian cashew sectors

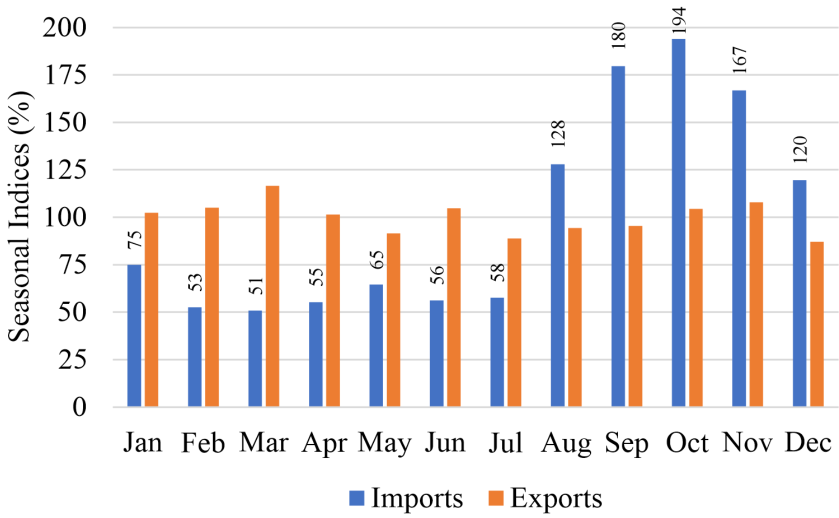
Year	World				India							
	Production (000 t)	Import (000 t)	Export (000 t)	Consumption (000 t)	Production (000 t)	Import (000 t)	Production + import (000 t)	Export (000 t)	Share of import (%)	Consumption (000 t)	Share of export (%)	Share of domestic consumption (%)
	(W_1)	(W_2)	(W_3)	(W_4)	(I_1)	(I_2)	$(I_3) = (I_1)+(I_2)$	(I_4)	$(I_5) = (I_2)\div(I_3)$	(I_6)	$(I_7)^{\S}$	$(I_8) = 100\% - (I_7)$
2007–08	2,789.06	603.96	391.07	486.68	665.00	624.93	1,289.93	112.73	48.45	274.25	29.13	70.87
2008–09	3,098.31	632.56	404.67	538.47	695.00	676.09	1,371.09	110.89	49.31	300.43	26.96	73.04
2009–10	3,196.09	772.84	412.51	523.51	613.00	723.87	1,336.87	110.72	54.15	290.34	27.61	72.39
2010–11	3,060.23	469.90	403.06	469.09	653.00	494.13	1,147.13	100.76	43.08	243.38	29.28	70.72
2011–12	3,244.72	864.75	416.43	576.43	725.00	830.77	1,555.77	116.44	53.40	350.29	24.95	75.05
2012–13	3,012.23	1,223.47	416.75	599.03	752.00	904.05	1,656.05	98.89	54.59	397.93	19.90	80.10
2013–14	2,971.08	1,227.50	429.12	601.64	753.00	865.56	1,618.56	107.63	53.48	377.94	22.17	77.83
2014–15	2,981.13	1,526.96	533.43	716.68	745.00	946.33	1,691.33	111.08	55.95	396.32	21.89	78.11
2015–16	3,394.72	1,917.43	555.24	724.56	671.00	801.12	1,472.12	87.08	54.42	354.56	19.72	80.28
2016–17	3,115.48	1,786.14	557.64	783.99	745.00	807.69	1,552.69	83.41	52.02	382.40	17.91	82.09
2017–18	3,655.79	2,035.22	584.28	721.23	817.00	703.61	1,520.61	71.87	46.27	384.31	15.75	84.25
2018–19	4,022.56	1,674.33	494.78	721.13	743.00	855.87	1,598.87	64.49	53.53	415.18	13.44	86.56
2019–20	3,773.10	2,191.20	689.29	830.47	703.00	890.87	1,593.87	59.10	55.89	419.06	12.36	87.64
2020–21	4,180.99	2,157.20	692.20	846.81	738.00	925.66	1,663.66	50.40	55.64	448.70	10.10	89.90
2021–22#	-	-	-	-	774.00	681.99	1,455.99	45.27	46.84	391.53	10.36	89.64
Exponential growth rate (%)	2.43***	12.26***	4.51***	4.53***	1.02**	1.78*	1.41**	-6.24***	0.36 NS	3.27***	-7.54***	1.83***
Cuddy-Della Valle instability index (%)	7.42	17.64	8.69	6.62	5.79	16.33	8.53	11.60	7.76	9.45	9.10	1.97

Source Ministry of Agriculture and Farmers Welfare, GoI, Food & Agricultural Organization; International Nut and Dried Fruit Council Foundation, Spain

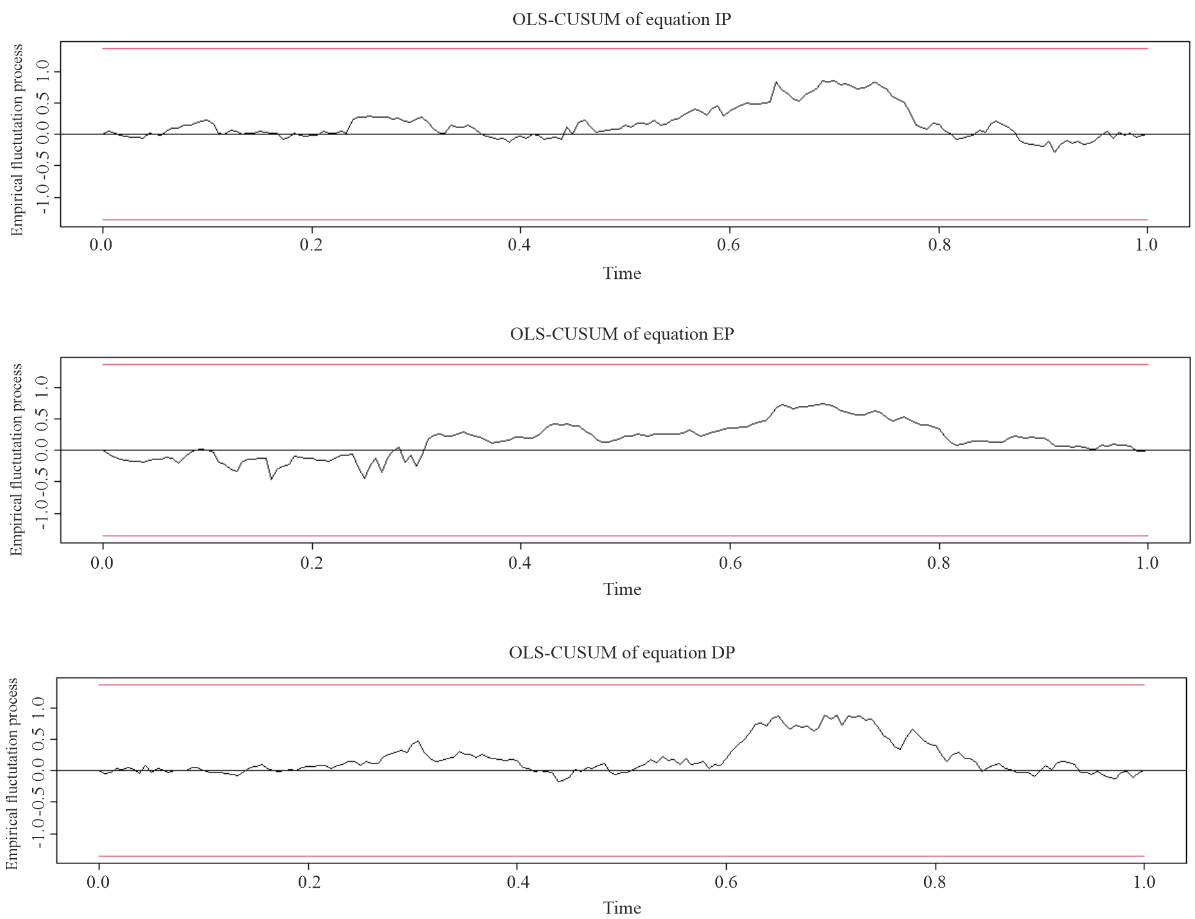
Note Export and consumption refers to cashew kernels; production and import refers to RCN and # indicates the 1st advance estimates.

*, ** and *** indicate 10%, 5% and 1% level of significance, respectively.

§Column (I_7) refers to $\frac{(I_4)}{(I3) \times 0.30} \times 100$



Supplementary Figure 1 Seasonal indices for quantities of RCN imports and cashew kernel exports from India (January 2007–April 2022)
Source Authors' estimates



Supplementary Figure 2 Results from structural stability test of the VAR model
Source Authors' estimates
Note OLS-CUSUM refers to ordinary least square cumulative sum

Agricultural Economics Research Review 2024, 37 (1), 93-112
DOI: 10.5958/0974-0279.2024.00004.4

Public investment in irrigation across the Indian states: Financial recovery and governance§

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Abstract This paper measures the financial recovery from major, medium, and minor irrigation systems in 20 states in India based on the estimates of public expenditure from 1981-82 to 2019-20. The role of governance in improving the performance of public irrigation is also analysed. The irrigation governance index is computed based on 16 important social, economic, and financial indicators collated for each state from 2001-02 to 2015-16. The analysis shows a sizeable increase in the public expenditure on agriculture and allied activities, major, medium, and minor irrigation systems during the 2000s. Agriculturally advanced states spent relatively more on irrigation due to their higher economic growth and hence better spending power. Increasing public capital formation in irrigation has barely corresponded with the outcomes in terms of net irrigated area, potential utilised, and rate of financial recovery. Irrigation financial recovery is positively determined by agricultural income, capital stock, area under rice and wheat.

Keywords Agriculture, canal irrigation, public investment, governance

JEL codes Q15, H54, O16, Q18

Introduction

This paper quantifies the financial recovery from major, medium and minor irrigation systems at the state level in India. It also examines the role of governance in improving the financial recovery from these public irrigation systems. The descriptive and empirical analysis is done from 1981-82 to 2019-20 across 20 major states, which cover nearly 90% of India's net sown area. The time series data on public expenditure on revenue and capital accounts are used to analyse the trends in public investment and governance issues. This study assumes importance as many state governments have increased budgetary outlays for the development of agriculture and irrigation during recent years, but the canal irrigation system, among other constituents, has been marred with large inefficiency. The inefficiency in canal irrigation can be explained by long gestation period in the construction of dams, cost overruns, inadequate management practices, and low operation and maintenance services due to insufficient funds (GoI, 1992; Gulati et al., 1994; Easter and Liu, 2005; Gulati and Banerjee, 2017). The canal irrigation system is also affected by low recovery rates due to subsidised water user charges, inefficiency in the distribution of water, and environmental externalities. As a result of these factors, the annual outlays directed towards irrigation barely correspond with the expected outcomes in terms of increase in the irrigated area and water use efficiency.

At the national level, only 46% of the net sown area (141 million ha) is irrigated. There has been a sluggish increase in the share of canal irrigated area (CIA) in the net sown area (NSA) from an average of 10.73% during 1982-86 to 12.56% during 2012-16. The official

§This paper is drawn from the ICAR-NIAP awarded research project - Irrigation Investments, Governance and Agricultural Outcomes: A State Level Analysis. The authors are grateful to Dr. Suresh Pal for his critical comments.

data (furnished in Annex Table 1) shows that the share of CIA in the net irrigated area (NIA) has consistently decreased from 36.60% to 25.94% during this period. Concomitantly, the net irrigated area by groundwater through tubewells has almost doubled in comparison to the area irrigated by canals. The area irrigated by tubewells has increased annually by 2.5%, whereas the area under canal irrigation has hardly increased at 0.6% during the same period. There also exists large inter-state differences in the percentage share of canal irrigated area in the net sown area as well as net irrigated area.

Various studies show that the use of surface water is unattractive to farmers, perhaps due to under-utilisation of over-capitalized irrigation infrastructure, inter-state disparities in public irrigation investments, inequality in the distribution of water, high level of bureaucracy, lack of regular water supply and poor maintenance of canal networks. To meet the growing demand for irrigation water, farmers have resorted to groundwater resources using electric and diesel tubewells. An increase in groundwater irrigation investment by the farmers can also be explained by affordable pump sets and the availability of power and diesel at subsidised rates (Joshi and Agnihotri, 1984; Pandya and Talati, 2007; Mukherji, 2016). However, the larger issue is the fall in public capital investment in irrigation in several states, which seems to have affected private investment and agriculture development, especially in the eastern states (Bathla and Aggarwal, 2021). Though concerted efforts have been made to increase investment in irrigation across the states for the completion of pending irrigation projects[1] since the mid-2000s, a low irrigation intensity continues to persist. This implies the existence of inefficiency in public investment in canal irrigation systems. Besides, many states have low utilisation of irrigation potential created; there are safety risks due to recurrent dam failures, and consequent floods result in the loss of lives.

Various studies have suggested improving the working of departmental commercial undertakings in the distribution of water and maintenance of canal networks and also the water use efficiency through technological interventions. It is shown that efficiency in the public irrigation system can be improved through an increase in resource allocation and completion of existing major-medium irrigation projects, charging the water users at least the operation and maintenance cost, if not the full cost of irrigation water supplied, follow good governance principles in the institutions/organisations and encourage investments in institutions to allocate water through community participation (self-help-groups or water user associations)[2]. At the policy level, the Y K Alagh Committee advocated a strong need for a National Water Framework Law (GoI, 2013). Shaw (2016) recommended the creation of a National Water Commission that unifies the Central Water Commission and Central Groundwater Board under one umbrella as part of improving the governance in the backdrop of the draft on the National Water Framework Bill, and the Model Bill for the Conservation, Protection, Regulation and Management of Groundwater, 2016.

The concept of governance is understood as the traditions and institutions by which authority is exercised. It may include a government's capacity to formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions (Kaufmann et al., 1999). Accordingly, the present study considers three broad dimensions of governance viz. (a) institutions and regulatory mechanism; (b) participation and accountability; and (c) service delivery. These dimensions captured using various social, political and economic indicators, help to gauge the level of irrigation governance across the states and analyse their impact on the outcomes.

Broadly, irrigation water governance points to four major institutional issues: (a) sectoral, segmented nature of institutions and their supply-side focus, (b) multiplicity of functions of different agencies, (c) poor water resource monitoring and distribution, and (d) centralised planning (Narian, 2000; Gulati et al., 2005; Ballabh, 2007; Kumar, 2010; Shah, 2011; Shah, 2016 & 2019). These aspects indicate that good governance can be fostered through better institutional arrangements in the management and distribution of

[1]The funds are routed under the Accelerated Irrigation Benefits Programme, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Har Khet Ko Pani, and creation of Long Term Irrigation Fund through NABARD.

[2]See among others, Saleth and Dinar (1999), Shah (2016), Gandhi and Johnson (2019).

public canal water rather than merely augmenting the supplies only. Better irrigation governance and water management practices are crucial in improving the utilisation of irrigation potential created and enabling higher agricultural productivity. While analysing public spending on major, medium and minor irrigation projects across the Indian states, Kannan et al. (2019) found a significant impact of irrigation governance on the performance of public irrigation systems, which in turn, can contribute to higher agricultural productivity.

In this research, we estimate the financial recovery from the major, medium and minor irrigation systems across major states in India. We also analyse the role of governance in bringing improvements in the financial recovery. The rest of the paper is organised as follows. Section II analyses the temporal and spatial trends in public investments in agriculture and irrigation from 1981-82 to 2019-20. Section III quantifies the financial recovery from major, medium and minor irrigation systems across the states and empirically estimates the determinants of irrigation financial recovery. Section IV highlights the role of governance and institutional reforms in bringing investment efficiency in the public irrigation system. Section V provides the main findings of the study.

Temporal and spatial trends in public investment in agriculture and irrigation

The trends in public expenditure in agriculture and irrigation are analysed for the period 1981-82 to 2019-20 across 20 major Indian states. The data are sourced from the Finance Accounts published by the Comptroller and Auditor General of India (CAG), Government of India (GoI). Public expenditure is given as per the revenue and capital heads under various social and economic services. Capital expenditure represents physical investment or gross capital formation[3]. As per the budgetary classification, the expenditure on irrigation segment includes (a) minor irrigation, (b) medium irrigation, (c) major irrigation, (d) Command Area Development, and (e) flood control. Expenditure on agriculture and allied heads covers twelve items; the major ones are crop husbandry, animal husbandry, soil conservation, research and extension, food-storage warehousing, fishery and forestry. Agriculture and irrigation are the state subjects in India. The central government provides financial outlays to states and also spends directly on many economic and social services in rural areas. The funds are largely routed through the state budgets. In this study, expenditures by the central government on major projects, loans and advances in agriculture and irrigation are not taken into consideration to avoid double counting. The data are deflated using the gross state domestic product (GSDP) deflator at 2011-12 prices, sourced from the National Accounts Statistics, Ministry of Statistics and Programme Implementation. The newly formed states, viz. Telangana, Chhattisgarh, Jharkhand, and Uttarakhand are merged with their respective parent states of Andhra Pradesh, Madhya Pradesh, Bihar, and Uttar Pradesh to maintain consistency in the time series data.

Public expenditure data given in GoI Finance Accounts show that on average, the state governments allocated 25% of total expenditure to irrigation and flood control followed by 19.2% on agriculture and allied activities. The amount spent on irrigation-flood control and agriculture heads has more than doubled during the 2000s, but their share in total expenditure had decreased considerably. It can be explained by low growth in capital expenditure (mainly on asset formation) in irrigation projects and an increase in revenue expenditure, which is mainly incurred to meet the day-to-day expenses and expenditure on input subsidy. Taking public expenditure (revenue + capital) on agriculture and allied activities, we find it to have increased from Rs. 145 billion in the triennium ending (TE) 1983-84 to Rs. 1407 billion in TE 2019-20 at 2011-12 prices. This expenditure has grown at an annual rate of 5.66% at 2011-12 prices. In contrast, the spending (revenue + capital) on irrigation and flood control has increased from Rs.240 billion in TE 1983-84 to Rs.810 billion by TE 2019-20 at 2011-12 prices. During the period the growth rate of irrigation and flood control has grown at a modest rate of nearly 3.5% per annum

Considering only the capital expenditure (broadly taken to be investment), its share in total spending on

[3]Capital expenditure is gross expenditure and this may include government's investment in financial stocks. Hence, it may be an over-estimation of actual investment in the respective heads/services. Government may not make financial investments in agriculture and irrigation sectors.

Table 1 Public investment in agriculture & allied activities, irrigation and flood control at 2011-12 prices

States	Agriculture & Allied Activities, Irrigation & Flood Control (Rs. Million)			Agriculture and Allied Activities only (Rs./ha)			
	TE 1983-84	TE 2015-16	TE 2019-20	TE 1983-84	TE 2003-04	TE 2015-16	TE 2019-20
Andhra Pradesh	13322	64843	64412	12.2	35.1	48.12	285
Assam	4548	9718	6466	148.11	4.06	75.96	662.83
Bihar	15193	16833	17344	70.54	11.52	651.53	898.62
Gujarat	12126	74295	80771	155.76	196.96	738.85	631.58
Haryana	6214	2783	27458	60.68	-824.34	-1401.32	5173.10
Himachal Pradesh	774	2793	4243	589.94	558.75	672.73	979.78
Jammu & Kashmir	2285	7403	9348 **	354.83	2540.51	6259.03	8179 **
Karnataka	9197	60203	89043	20.71	34.57	197.45	178
Kerala	5568	6356	6535	302.21	321.92	1574.29	1938
Madhya Pradesh	15645	41269	61033	56.34	38	83.03	400
Maharashtra	19870	88074	114399	50.85	340.05	1317.16	2122
Odisha	16307	28933	46852	122.85	166.5	434.51	371
Punjab	4899	7241	14668*	-6.92	-572.89	181.45	120.15
Rajasthan	9396	14107	18900	23.89	33.24	213.92	135.35
Tamil Nadu	4036	15498	21285	262.13	346.45	1522.36	1627.95
Uttar Pradesh	19410	44625	57339	-29.03	636.42	689.81	1381.87
West Bengal	2277	15312	17331*	99.02	41.69	1040.12	784.47*
Chhattisgarh	—	14424	11708	-	84.04	126.02	144.14
Jharkhand	—	6339	14310	-	2.53	458.65	2153
Uttarakhand	—	8262	9530	-	55.86	3744.02	10234
Bihar & Jharkhand	15193	23173	31654	70.54	8.14	607.3	1165
MP & Chhattisgarh	15645	55694	72742	56.34	39.55	93.05	340
UP & Uttarakhand	19410	52887	66869	-29.03	584.54	812.43	1720
AP & Telangana	13322	100201	146054	12.2	35.1	70.23	545
All 20 States	156640	564521	745586	63.33	154	544.91	988

Source: Finance Accounts, GoI: * refers to the average of 2015-16 and 2016-17; ** refers to TE 2017-18; NSA is taken to estimate investment on a per ha basis.

agriculture and allied activities has been very low. The same in the case of irrigation and flood control is relatively much higher due to the nature of activities in this sector. The estimates presented in Table 1 show capital expenditure (i.e. investment) in agriculture and irrigation together has increased from Rs. 156.64 billion in TE 1983-84 to Rs. 564.52 billion in TE 2015-16 and then to 745.59 billion in TE 2019-20. The estimates show large inter-state variations in public investment in agriculture and irrigation together. The states - Gujarat, Karnataka, Maharashtra, MP-Chhattisgarh and AP-Telangana which are relatively more advanced in agriculture, have allocated more funds towards asset formation. In terms of the annual rate of investment growth, Annex Table 2 shows a higher growth in it, close to 7% in Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu. The rate of growth has gone up more than 10% during the 2000s in almost all the states. However, irrigation investments in three states, viz. Haryana, Punjab, Rajasthan and Uttar Pradesh are lower owing to financial and various other reasons (Bathla et al., 2021)[4]. Surface irrigation

[4]Andhra Pradesh, Karnataka and Maharashtra resolved interstate disputes on Krishna in 1979-80 and Gujarat could settle Narmada dispute. In contrast, Haryana and Rajasthan have shortage of water as it is available through Indus system, which is tightly allocated with additional allocations under severe disputes. Similarly, Uttar Pradesh though in an advantageous position with respect to irrigation systems have problems in harnessing water in the absence of cooperation with the neighbouring countries.

investment is lower in the hilly states. Investments in Bihar, Assam, Odisha, Tamil Nadu and West Bengal are way behind as compared to other states. These states should give more priority to spending on irrigation, mainly on capital expenditure to trigger agricultural growth.

Given the large inter-state differentials in public expenditure on agriculture and allied activities and irrigation, Table 1 also provides public expenditure estimates on a per hectare (ha) basis in agriculture and allied activities. We find that for all the selected 20 states together, the average per ha investment in agriculture and allied activities has increased from Rs. 63.33 in TE 1983-84 to Rs. 545 in TE 2015-16. It has almost doubled to Rs.988 in TE 2019-20. Among the selected states, J&K, Kerala, Maharashtra, Tamil Nadu and Uttarakhand have invested more than Rs.1000 per ha in these heads in recent periods. A significant increase in investment in agriculture and allied activities is identified in Andhra Pradesh, Assam, Himachal Pradesh, Haryana, Madhya Pradesh, Jharkhand, and Uttar Pradesh.

Similarly, on irrigation expenditure, almost every state had considerable investment during the 1980s, which significantly fell during the nineties and slightly recovered from the mid-2000s. Here, we have considered irrigation investment in stock terms due to considerable lag in the completion of projects and hence excluded expenditure on flood control. For 20 states taken together, Table 2 shows an increase in per ha investment from Rs. 14,889 in TE 1983-84 to Rs. 18760 in TE 2015-16 and to Rs. 24081 in TE 2019-20. The southern states have much higher investments in irrigation compared to the northern states, which is perhaps due to higher economic growth in these states and hence their better spending power. The low per ha investment states are Rajasthan, Assam, Bihar, Haryana, Punjab, Kerala, Madhya Pradesh, Uttar Pradesh and West Bengal. Irrigation investments in major and medium irrigation systems are much higher (Rs. 19667/ha) compared to that in the minor irrigation head (Rs. 4251/ha), except in Assam and other hilly areas. The government also invests in command area development under the irrigation and flood control head. However, there is lesser capital formation under this category of irrigation.

Among various heads of irrigation expenditure, the average share of expenditure on medium and major irrigation systems in total irrigation expenditure is the maximum at 40%. It may be due to the accelerated irrigation benefit programme (AIBP) providing grant-based funds and also a provision of the Prime Minister package for distressed areas. The low per capita income states, viz. Bihar, Uttar Pradesh, Assam, and Madhya Pradesh spend more on minor irrigation accounting for nearly 30% of total irrigation expenditure during TE 2019-20. J&K also registered a higher public expenditure on minor irrigation in TE 2015-16 compared to earlier period. In contrast, the middle-income states, viz. Odisha, Rajasthan, West Bengal, Andhra Pradesh, and Karnataka and high per capita income states, viz. Punjab, Himachal Pradesh, Tamil Nadu, Kerala, Gujarat, Haryana, and Maharashtra spend only 5% and 17% of total expenditure on minor irrigation. The share of expenses of a few states on flood control was significant at 63%.

Notably, the real annual rate of growth in minor irrigation, mainly tanks and tubewells is much higher at 12% compared to the growth rate in major and medium irrigation systems at nearly 6%. Efficiency of investment was found to be more in minor irrigation schemes; relatively it is still high in drip and sprinkler irrigation implying the need to scale up their area coverage (Kannan, 2018). An increase in investment in minor irrigation may be attributed to the long gestation period for the completion of the canal network and the operational inefficiency therein. The presence of large inter-state differences in public investment in agriculture and irrigation in India was due to historical and climatic factors and hence difficult to bridge them (Bathla et al., 2020).

Overall trends show that public expenditure on agriculture and irrigation (revenue + capital) has significantly increased in all the states from the early 2000s and the increase in capital investment in less developed, agriculturally dependent states of Odisha and Bihar is appreciable. Nevertheless, we do not find much increase in the capital intensity. The estimates furnished in Table 3 show that from TE 1983-84 to TE 2019-20, the share of capital expenditure in the total expenditure on agriculture (revenue + capital) has increased from 6.26% to 10.8% and on irrigation from 61.09% to 75.24%. If we exclude expenditure on flood control from the irrigation head, capital intensity has remarkably increased over the period to reach 75%. The share of investment decreased to 47% during the

Table 2 Public Investment on Irrigation (Rs./ha) at 2011-12 prices

States	Major-Medium Irrigation			Minor irrigation			Command Area Development			Total Irrigation		
	TE 1983-84	TE 2015-16	TE 2019-20	TE 1983-84	TE 2015-16	TE 2019-20	TE 1983-84	TE 2015-16	TE 2019-20	TE 1983-84	TE 2015-16	TE 2019-20
Andhra Pradesh & Telangana	16254	43878	64247	1655	5044.15	9700.30	373.47	34.68	21.40	18282.72	48956.49	73969.08
Assam	6808	1324	1198	9109	9126.35	10986	926.09	93.87	132.66	16842.48	10544.23	9649
Bihar-Jharkhand	21895	9258	12920	2415	2084.3	3021.68	4.56	17.75	10.50	24314.49	11359.54	15952.52
Bihar	21895	8054	8753	2415	1369.83	1564	4.56	0.03	0.01	24314.49	9423.85	10318
Gujarat	11830	27457	36221	459	4666.58	5384	0.29	0	0	12290.26	32123.78	41605
Haryana	16663	12025	12646	1595	202.2	114.28	0	0	0	18258	12227.29	12760
Himachal Pradesh	2227	6555	5436	6523	12980.6	15056	73.79	1140.27	2291	8824.29	20675.96	22783
Jammu & Kashmir	17253	5342	4809 *	7141	11748.23	10966 *	0	2284.35	2043.21*	24394.36	19374.3	17817.98*
Karnataka	10938	26087	33762	1546	4407.77	6532.92	0	167.24	357	12483.76	30661.76	40652.58
Kerala	24209	4736	4291	1626	1824.25	3119.96	0	0	0	25835.66	6560.24	7411.17
Madhya Pradesh	7450	9299	14520	2821	2774.82	2955.93	150.3	217.1	400	10422.13	12290.44	17876.44
Maharashtra	11134	25561	28096	1423	2711.78	3533.18	4.65	0.08	0.05	12562.06	28272.33	31629.54
MP-Chhattisgarh	7451	8477	13131	2821	4209.38	4544.81	150.3	277.66	395.06	10422.13	12964.45	18070.97
Odisha	17481	18316	30634	2559	4486.87	15064.14	0.21	0.01	0.01	20041.46	22802.62	45698.40
Punjab	12930.16	4601.81	4673**	1036.78	481.98	484.1**	1.41	1498.59	2002 **	13968.35	6582.38	7158.99
Rajasthan	6207.2	2375.63	3212	740.86	820.42	1088.57	456.84	343.75	341	7404.9	3539.8	4642.28
Tamil Nadu	6956.73	7442.78	10664	154.81	1381.48	1320.94	156.19	343.63	270	462.52	9136.82	12236.72
UP & Uttarakhand	11450.15	7207.85	9645	3407.61	1774.05	1782.30	45.42	0.23	0.13	14903.17	8982.13	11427.44
Uttar Pradesh	11450.15	6685.13	9118	3407.61	1365.77	1467.22	45.42	0.24	0.14	14903.17	8051.14	10585.45
West Bengal	3337.6	1299.52	1332 **	62.83	1528.09	2565.32**	68.33	104.71	103.51	3462.4**	2932.28	4000.45
All 20 States	12479.79	14512.55	19667	2598.86	3936.08	4251	135.01	313.49	223	14889.31	18760.63	24081.96

Note Irrigation investment is measured in stock; Public investment in irrigation excludes flood control. Major and medium irrigation categories are clubbed as expenditure on major irrigation is given from 2010.
Source Finance Accounts, GoI. Note: * refers to average TE 2018-19; ** refers to average 2015-16 & 2016-17

Table 3 Capital Intensity of Public Expenditure on Agriculture and Irrigation (denoted by% share of capital expenditure in revenue + capital expenditure)

States	Agriculture & Allied Activities				Irrigation (excluding flood control)			
	TE 1983-84	TE 2003-04	TE 2015-16	TE 2019-20	TE 1983-84	TE 2003-04	TE 2015-16	TE 2019-20
Andhra Pradesh & Telangana	1.61	2.18	1.01	4.14	56.71	43.71	62.69	94.89
Assam	5.73	0.15	0.7	7.19	83.14	55.74	63.21	55.40
Bihar	6.8	1.48	10.93	14.17	74.94	49.17	54.62	52.07
Gujarat	24.42	13.2	17.24	9.79	52.94	43.62	88.34	89.19
Haryana	2.94	-2131.22	-78.17	42.08	52.09	35.43	36.21	39.90
Himachal Pradesh	8.61	3.79	2.78	3.25	60.02	40.98	31.04	42.46
Jammu & Kashmir	6.4	15.59	26.49	25.24*	63.21	27.62	37.39	25.42*
Karnataka	2.88	1.7	2.04	1.34	56.83	90.3	87.82	85.52
Kerala	11.18	5.52	8.12	9.13	73.67	49.07	35.32	34.76
Madhya Pradesh	6.46	2.98	2.16	5.98	80.13	77.16	86.41	90.05
Maharashtra	3.44	12.56	22.99	17.38	62.64	63.75	74.09	82.74
Odisha	11.57	8.72	10.43	2.31	86.34	73.12	64.83	76.50
Punjab	-9.51	472.13	3.15	1.38**	57.97	41.56	25.03	36.16**
Rajasthan	7.95	4.73	10.44	4.56	56.57	39.76	40.84	54.99
Tamil Nadu	12.62	7.93	10.56	7.49	38.96	36.63	40.83	52.80
Uttar Pradesh	-8.41	28.37	20.32	20.88	51.65	33.13	40.42	35.64
West Bengal	9.97	2.39	20.52	62.62 **	27.98	20	38.94	54.57**
Chhattisgarh	-	3.16	1.07	0.69	-	72.11	78.41	71.41
Jharkhand	-	0.08	5.55	15.31	-	84.57	62.8	78.92
Uttarakhand	-	0.65	17.98	25.87	-	21.77	54.18	35.45
Bihar& Jharkhand	6.8	0.75	9.6	14.80	74.94	60.51	58.26	66.66
Madhya Pradesh & Chhattisgarh	6.46	2.96	1.62	3.15	80.13	75.69	84.33	86.43
Uttar Pradesh& Uttarakhand	-8.41	24.25	20.28	21.24	51.65	32.39	41.58	35.63
All 20 States	6.26	7.21	8.8	10.0	61.09	54.12	65.38	75.24

Note Public investment in irrigation excludes flood control; Source: Based on Finance Accounts, GoI;
* refers to TE 2018-19; ** Average 2016-17 & 2017-18

mid-1990s and to 54% during the 2000s and it started reviving in the late 2000s. Only in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan and Tamil Nadu, capital deepening in irrigation is visible.

A lower share of investment in total expenditure implies that a significant amount of resources is devoted towards meeting the administrative, operational or maintenance expenditure, including subsidies. It may also imply the mounting inefficiency and overheads, especially in major and medium canal irrigation systems, and hence cost escalation. A reduction in expenditure on capital account may be aimed at achieving the targeted fiscal deficit. Moreover, Bathla et al. (2021) have pointed towards persistent inefficiency in public irrigation expenditure from 1981-82 to 2015-16. The authors quantified technical efficiency (TE) in irrigation expenditure by taking both capital (investment) and revenue expenditure heads. The results indicate that on average for 20 major states, canals operate at about 59% efficiency in water use, although levels vary widely, from 10% and 16% in Andhra Pradesh and Himachal Pradesh to 100% each in J&K, Madhya Pradesh and West Bengal. The latter two states along with Rajasthan, Odisha and Karnataka tend to be more efficient in spending on canal irrigation compared to Andhra Pradesh, Himachal Pradesh, Uttar Pradesh, Kerala, Maharashtra & Assam. The results also depict that Haryana, Himachal Pradesh, Punjab, Kerala, Maharashtra and Uttar Pradesh are at the low end of the efficiency scale (below the national average). It implies that the potential for easier gains through technical efficiency tends to be higher in these states. At the other end of the scale, the above-mentioned states have operated at relatively higher levels of efficiency, suggesting little scope for improvement. The sub-period analysis shows an increase in efficiency is achieved mainly in Kerala, Gujarat, Bihar, Karnataka, Odisha, Rajasthan, Madhya Pradesh and West Bengal. Furthermore, the inefficiency in canal irrigation is more due to capital expenditure which has also increased over the period. These results have implications for improving project governance and the fact that public policy should focus more on outcomes rather than on outlays.

Financial recovery from the canal irrigation system

Financial recovery is an important indicator of the performance of India's irrigation system. This has been estimated based on the cost of provision of irrigation water and charges levied on the users of irrigation water. Analysis of the financial position of the public irrigation sector helps to understand the capacity of the sector to provide adequate irrigation water to farmers on time, maintain and repair canals, and strengthen institutional mechanisms for the sharing of water equitably among the farmers. In the present study, the financial recovery rate is computed as the ratio of receipts accrued to irrigation schemes to operational expenditure incurred on the schemes. Receipts from the irrigation sector constitute user fees collected from the farmers for using canal water and other miscellaneous revenues, whereas operational expenditure is the amount spent for regular maintenance and repair of water channels, and manpower engaged. Data on receipts and operational expenditure (revenue expenditure) from various irrigation schemes were compiled from the Finance Accounts published annually by the Comptroller and Auditor General of India, Government of India.

Analysis of irrigation recovery rate at all India level

Details of receipts, operational expenditure and recovery rate at all India level are presented in Table 4. The operational expenditure on major and medium irrigation in real terms has increased by two and half times between TE 1985-86 and TE 2015-16, from Rs. 67,223 million to Rs. 174,896 million and then decreased to Rs. 130,316 million in TE 2019-20. The receipt from major and medium irrigation schemes has also increased from Rs. 11,435 million to Rs. 43,552 million at 2011-12 prices. Although an increase in the receipts in absolute value is less than the operational expenditure, the rate of increase in the receipts is found to be much higher. Consequently, the recovery rate in the major and medium irrigation projects has improved from 17.01% in 1985-86 to 24.49% in 2015-16 and then to 33.25% in 2019-20, although there was a slump in the recovery of the expenses during 2003-04.

Table 4 Financial Recovery of Irrigation, GSDPA and Canal Area in All India (20 States) at 2011-12 prices

Particulars	Irrigation Projects	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20
Receipt	Major and Medium	11435	13800	41342	43552
(Rs Million)	Minor	2702	1662	6490	6108
	All	14136	15462	47832	49661
Operational	Major and Medium	67223	132122	174896	130316
Expenditure	Minor	26018	30388	52980	53051
(Rs Million)	All	93241	162510	227875	183367
Recovery (%)	Major and Medium	17.01	11.04	24.49	33.25
	Minor	10.35	5.52	12.58	11.61
	All	15.11	9.95	21.63	26.97
GSDPA Per Hectare		33130	59251	116036	131259*
Canal Area (000 hectare)		16028	15342	17581	18105

Source Finance Accounts, CAGI, and Ministry of Agriculture & Farmers Welfare, Government of India
Note * refers to GVA

In the case of minor irrigation projects, the real operational expenses have marginally increased from Rs. 26,018 million in TE 1985-86 to Rs. 30,388 million in TE 2003-04, which further increased steeply to reach Rs. 53,051 million in TE 2019-20. This rise in operational expenditure on minor irrigation indicates the importance given to the development of minor irrigation by the government during the recent decades. However, the recovery of expenses incurred on minor irrigation structures is not encouraging. Despite some improvement in the receipts, a higher proportional rise in the operational expenditure led to slow improvement in the financial situation with the recovery rate improving only marginally from 10.35% in 1985-86 to 11.61% in 2019-20.

Taking all the irrigation projects together, there was an increase in the recovery of operational expenditures from 15.11% to 26.97%. The recovery rate was low during the early 2000s, which could be attributed to the poor performance of GSDP agriculture and allied activities during the eighties and the nineties, leading to a fall in income per hectare. This poor performance could also be seen in terms of the contraction of canal irrigated area. However, there seems to be some revival in the expansion of agricultural income and canal irrigated area from the early 2010s.

Analysis of irrigation financial recovery rate at the state level

There is considerable variation in the amount of receipts, operational expenditure and recovery rate in major and medium irrigation projects across the states. The operational expenditure at 2011-12 prices was the highest at Rs. 54,921 million in Andhra Pradesh followed by Rs. 27,974 million in Uttar Pradesh, Rs. 15,556 in Maharashtra and Rs. 13,052 billion in Rajasthan during 2015-16 (Table 5). A significant change in the order of states in terms of operational expenditure during the recent period with the highest expenditure incurred in Uttar Pradesh followed by Rajasthan and Maharashtra is observed. We also find a considerable increase in the operational expenses of major and medium irrigation projects in the state of Andhra Pradesh between 1985-86 and 2015-16, but it fell sharply in 2019-20. A consistent increase in the operation and maintenance costs could be observed in Haryana, Odisha, Tamil Nadu and Uttar Pradesh. However, there is a near stagnation in operational expenses on major and medium irrigation projects in Madhya Pradesh between 2015-16 and 2019-20. The amount of operational expenditure has shown a declining trend in Maharashtra, implying efficient use of financial resources for creating irrigation infrastructure in the state.

Interestingly, the revenue accrued from major and medium irrigation projects has more or less increased in most of the states between 1985-86 and 2019-20. This shows improvement in the collection of user fees by various state agencies. Although canal water rates remain unrevised for a long time, an increase in revenue seems to be encouraging. There has been a phenomenal rise in the receipt from the major and medium irrigation projects in Jammu and Kashmir during recent years. An increase in the receipts could be attributed to income obtained from leasing out the waterbodies for fishing, navigation, industrial use and hydropower generation. Revenue accrued was far highest in Uttar Pradesh with Rs. 6187 million. However, it has fallen in Bihar, Karnataka and Maharashtra.

Low revenue realisation and high operational costs have resulted in low recovery rates in major and medium irrigation projects in many states. The recovery rate was more than 100% in Jammu and Kashmir, Gujarat, Jharkhand and Odisha. There is a consistent rise in the recovery rate in Gujarat from 5.40% in 1985-86 to 15.83% in 2003-04 and then to 238.80% in 2019-20. The rise in the recovery rate in these states is mainly due to an increase in income obtained from the irrigation projects relative to the cost incurred on their operation and maintenance. This may also imply efficient utilisation of canal water and its distribution by the local institutions and proper collection of water user fees. Other states, notably Assam, Bihar, Himachal Pradesh, Karnataka and Kerala have recorded a decline in the recovery of water charges over time.

Details of receipt, operational expenditure and recovery rate from minor irrigation projects are presented in Table 6. Among the states, the cost of operation and maintenance of minor irrigation structures was the highest in Uttar Pradesh with Rs. 18,949 million followed by Odisha (Rs. 4,535 million), Gujarat (Rs. 4,379 million) and Maharashtra (Rs. 3,988 million). The rise in expenses on minor irrigation seems to be more gradual over time. Perhaps, the importance of construction, revival and maintenance of minor

Table 5 Operational Expenditure, Receipt and Recovery Rate in Major & Medium Irrigation, Rs. million at 2011-12 Prices

States	Receipt (Rs Million)				Operational Expenditure (Revenue Expenditure) (Rs Million)				Recovery Rate (%)			
	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20
Andhra Pradesh**	1305	199	1633	5208.43	9155	27066	54921	6166	15.60	0.74	3.38	79.1
Assam	23	4	5	6.37	90	368	983	1072	25.6	1.09	0.51	0.59
Bihar	570	334	75	279.57	2194	2653	3556	3048	26.0	12.59	2.11	9.2
Gujarat	511	3283	8748	10350	9401	20735	5042	4342	5.4	15.83	173.50	238.8
Haryana	757	1824	936	1145.39	4214	6682	8980	9802	18.0	27.30	10.42	11.7
Himachal Pradesh	0	64	2	4.47	0	52	185	222.3	-	123.08	1.08	2.7
Jammu & Kashmir	15	14	8013	5692.44*	260	376	582	585.13*	5.8	3.72	1376.80	976.8*
Karnataka	361	315	234	108.25	5494	1184	4552	11593	6.6	26.60	5.14	0.94
Kerala	85	76	94	160.25	473	1150	2011	2101	18.0	6.61	4.67	7.95
Madhya Pradesh	772	468	1153	1312.72	1998	3412	4992	4937	38.6	13.72	23.10	28.1
Maharashtra	880	2323	5069	1669.76	11359	19206	15556	12076	7.7	12.10	32.59	13.9
Odisha	384	441	5072	5301.74	505	1389	4593	5185	76.0	31.75	110.43	102.7
Punjab	854	304	809	671.08**	2976	4922	8847	7758**	28.7	6.18	9.14	11.7**
Rajasthan	884	531	612	1300.57	6250	12442	13052	12169	14.1	4.27	4.69	10.35
Tamil Nadu	89	182	363	303.23	2887	6642	9412	10525	3.1	2.74	3.86	2.88
Uttar Pradesh	3894	2025	3785	6186.85	8936	18788	27974	32496	43.6	10.78	13.53	19.04
West Bengal	49	43	90	64.48**	1032	1774	2134	2145**	-	2.42	4.22	1.73**
Chhattisgarh	-	841	3537	3611.29	-	1480	3084	3616	-	56.82	114.69	99.9
Jharkhand	-	378	1041	2691.10	-	276	2140	2362	-	136.96	48.64	114.4
Uttarakhand	-	151	70	57.11	-	1526	2300	2630	-	9.90	3.04	2.16
Bihar+ Jharkhand	570	713	1116	2970.67	2194	2929	5697	5409	26.0	24.34	19.59	123.6
MP+ Chhattisgarh	772	1310	4690	4924.01	1998	4892	8076	8553	38.6	26.78	58.07	58.85
UP + Uttarakhand	3894	2176	3855	6243.96	8936	20314	30273	35126	43.6	10.71	12.73	17.77
All States	11435	13800	41342	43552.12	67223	132122	174914.30	130316	17.0	10.44	23.64	33.25

Source Finance Accounts, Government of India.** Andhra Pradesh Includes Telangana. NA = Not Available;
Note * refers to TE 2018-19; ** refers to average 2016-17 – 2017-18

Table 6 Operational Expenditure, Receipt and Recovery Rate in Minor Irrigation at 2011-12 Price

States	Receipt (Rs Million)				Operational Expenditure (Revenue Expenditure) (Rs Million)				Recovery Rate (%)			
	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20
Andhra Pradesh**	55	26	160	33.71	2335	2066	2033	881	2.36	1.26	8.95	3.83
Assam	15	4	3	1.88	450	963	2902	3098	3.33	0.42	0.10	0.06
Bihar	67	17	34	80.86	2749	2161	2570	2377	2.44	0.79	1.32	3.62
Gujarat	66	100	144	422.81	1476	2030	3438	4379	4.47	4.93	4.19	9.18
Haryana	19	2	1	0.01	162	509	62	54	11.73	0.39	1.61	0.02
Himachal Pradesh	5	6	9	8.07	248	989	2552	2985	2.02	0.61	0.35	0.27
Jammu & Kashmir	14	19	67	52.02*	454	1629	2309	1916*	3.08	1.17	2.90	1.94*
Karnataka	43	65	97	185.29	1151	1517	1908	1929	3.74	4.28	5.08	9.41
Kerala	139	19	47	45.59	880	1031	1328	1516	15.80	1.84	3.54	3.05
Madhya Pradesh	250	156	2249	2474.98	1593	588	1021	1095	15.69	26.53	220.27	223.7
Maharashtra	216	183	710	441.44	2045	3109	6747	3988	10.56	5.89	10.52	11.53
Odisha	157	46	144	112.26	997	1488	5359	4535	15.75	3.09	2.69	2.52
Punjab	25	2	24	0.20 **	1047	834	1354	1143**	2.39	0.24	1.77	1.94**
Rajasthan	265	413	122	51.70	1039	1211	1430	1009	25.51	34.10	8.53	5.07
Tamil Nadu	142	72	17	21.16	591	562	745	741	24.03	12.81	2.28	2.85
Uttar Pradesh	1096	287	612	691.05	7583	4771	11606	18949	14.45	6.02	5.27	3.72
West Bengal	127	117	143	126.72**	1219	2967	3671	2817**	10.42	3.94	3.90	2.01**
Chhattisgarh	-	120	1869	1419.35	-	801	661	609	—	14.98	282.75	228.36
Jharkhand	-	2	20	26.21	-	448	597	611	-	0.45	3.35	4.23
Uttarakhand	-	6	18	14.75	-	714	686	811	-	0.84	2.62	1.85
Bihar+ Jharkhand	67	19	53	107.06	2749	2609	3167	2988	2.44	0.73	1.67	7.86
MP+ Chhattisgarh	250	277	4118	3894.33	1593	1389	1683	1704	15.69	19.94	244.68	228.76
UP + Uttarakhand	1096	293	630	705.79	7583	5486	12291	19759	14.45	5.34	5.13	3.64
All States	2702	1662	6490	6108.43	26018	30388	52980	53051	10.39	5.47	12.25	11.61

Source Finance Accounts, CAGI, Government of India.** Andhra Pradesh Includes Telangana. NA = Not Available
Note * refers to TE 2018-19; ** refers to average 2016-17 – 2017-18

irrigation systems caught the attention of the government during the recent decades only. The magnitude of expenses on minor irrigation structures was much lower than that of major and medium irrigation projects. Further, studies have shown that the cost of creation of irrigation potential was much lower in the case of minor irrigation projects than the major and medium irrigation systems.

The revenue from the minor irrigation system has increased in most states, but this increase was only marginal as compared to a rise in the operation and maintenance costs. The revenue realisation from minor irrigation was the highest in Madhya Pradesh and it increased phenomenally from Rs. 250 million in 1985-86 to Rs. 2,475 million in 2019-20 at 2011-12 prices. Among the states, Assam, Haryana, Kerala, Maharashtra, Odisha, Punjab, Rajasthan and Tamil Nadu have shown a decline in revenue realisation during the recent years.

Considerable increase in operational expenditure over time, and a slow rise in revenue realisation have affected the cost recovery from minor irrigation systems in most of the states. The recovery of operational expenditure was observed by more than 100% in Madhya Pradesh and Chhattisgarh. Barring Maharashtra, the recovery rate was less than 10% in all other states. For all the states together, the recovery rate was low at 11.61%. Minor irrigation systems comprising small water bodies are important for maintaining hydrological balance, recharge of groundwater, environmental protection and other social needs. Therefore, it is important to conserve these water bodies through government finances even if revenue accumulation through collection of fees from the users is low.

Farmers' ability to pay and irrigation financial recovery

The capacity of farmers to pay canal water fees depends on many factors. In the present study, two indicators, viz. per hectare gross state domestic product from agriculture and canal irrigated area have been considered as proxy for the capacity of farmers at the macro level. Here, an attempt has been made to find if there is any association between the recovery rate (operational efficiency) and per hectare agricultural income and canal irrigated area. Canal irrigation is likely to increase the income of farmers from an increase in cropping intensity and cultivation of remunerative crops.

Most states have registered a small increase in the per hectare agricultural income during TE 2003-04 as compared to TE 1985-86. At all India, the per ha agriculture income increased from Rs. 63,522 per ha to Rs. 65,251 during this period (Table 7). It may be due to an increase in the cost of inputs that isn't commensurate with the increase in the price of output and fewer policy reforms. The agriculture income per ha significantly increased to Rs. 150,253 per ha by TE 2010-20. It can be hypothesised that developed states with high levels of per hectare agricultural income (Andhra Pradesh, Haryana, Himachal Pradesh, Kerala, Punjab and Tamil Nadu) are likely to have farmers with more ability to pay canal water fees than the states with low level of agricultural income (Assam, Bihar, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Chhattisgarh). Similarly, the states with higher canal command areas are likely to have higher levels of financial recovery than the states with lower canal command areas.

The analysis shows that there is no definite association between recovery rate and per hectare real agricultural income at 2011-12 prices. For instance, Punjab with the highest level of agricultural income has a lower recovery rate of 10.40% in 2019-20. Similarly, Haryana and Tamil Nadu have relatively high agricultural income, but low financial recovery of cost from major and medium irrigation projects. On the contrary, Chhattisgarh had registered an irrigation financial recovery of more than 100%, but these states have lower per-hectare agricultural income. Although Uttar Pradesh has the highest level of area under canal irrigation with 2.5 million hectares in 2015-16, the recovery rate was as low as 13.4%. Similar evidence was found in Rajasthan and Andhra Pradesh. These results broadly imply that there is no association between the aggregate paying capacity of farmers and the recovery rate. Perhaps, low user fees, poor user charges, collection mechanisms and dysfunctional irrigation institutions contribute to low financial recovery in the major and medium irrigation projects.

Determinants of irrigation financial recovery

We estimate linear regression models to analyse the determinants of irrigation financial recovery by using state-level panel data. Both fixed effects and pooled

Table 7 Financial Recovery of Major, Medium & Minor Irrigation, GSDPA at 2011-12 Price and Canal Irrigated Area

States	Recovery (%)				Gross State Domestic Product Agriculture (GSDPA) Per Hectare				Canal Irrigated Area (Million hectare)		
	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16	TE 2019-20	TE 1985-86	TE 2003-04	TE 2015-16
Andhra Pradesh**	13.58	0.77	3.51	3.83	40778	81718	149299	229219	1805	1303	1643
Assam	7.08	0.67	0.21	0.20	53725	80855	121849	131050	362	33	78
Bihar	12.72	7.47	1.68	6.76	63522	75196	116614	140014	996	945	927
Gujarat	5.44	26.88	104.9	123.8	28881	46104	105239	136998	426	454	771
Haryana	17.70	26.04	10.4	11.62	56546	101479	186107	224690	1189	1417	1199
Himachal Pradesh	2.10	7.95	0.39	0.40	63965	149445	249261	264353	6	4	4
Jammu & Kashmir	4.24	1.67	269.43	175.22	74997	127327	173258	216242	288	281	289
Karnataka	6.18	14.02	5.67	2.17	29924	47813	76385	88788	700	806	1206
Kerala	17.08	4.31	4.22	5.94	101620	149064	221159	211046	101	101	84
Madhya Pradesh	28.41	15.60	58.43	65.20	13732	29001	79886	102451	1258	859	1614
Maharashtra	8.29	28.15	26.07	13.32	17412	38911	82505	103812	673	1001	1081
Odisha	35.89	17.19	52.78	58.23	41591	48716	102557	121240	968	920	826
Punjab	23.13	5.70	8.25	10.40	64337	115570	190207	220398	1430	1090	1147
Rajasthan	15.94	6.90	5.08	9.94	18899	36815	75826	88562	1110	1242	1895
Tamil Nadu	6.56	3.51	3.74	2.88	46062	68907	201162	254924	845	621	653
Uttar Pradesh	30.23	9.84	11.18	13.44	43019	73918	121489	136178	3339	2705	2521
West Bengal	7.83	3.49	4.00	1.90	42892	98241	247179	268583	722	673	672
Chhattisgarh	-	43.51	145.03	119	-	39515	66232	77422	-	779	887
Jharkhand	-	52.03	38.40	91.94	-	87559	194975	189829	-	15	6
Uttarakhand	-	6.95	2.94	2.08	-	103768	202641	213513	-	93	80
Bihar+ Jharkhand	12.72	59.50	40.09	98.7	63522	65251	132326	150253	996	960	934
MP+ Chhattisgarh	28.41	25.32	90.89	86.82	13732	26075	77061	96615	1258	1639	2501
UP + Uttarakhand	30.23	9.59	10.60	12.72	43019	70839	125435	139128	3339	2798	2601
All States	15.11	9.95	21.63	26.97	33130	59251	116036	131259	16028	15342	17581

Source Finance Accounts, CAGI, Government of India, Ministry of Agriculture & Farmers Welfare, GoI. NA = Not Available;
Note GSDPA/Ha for TE 2019-20 refers to GVA/ Ha.

ordinary least squares (OLS) methods are used for the estimation. The financial recovery ratio is used as a dependent variable. The independent variables are agricultural income per hectare, irrigation capital stock, rainfall, area under rice, wheat and sugarcane, number of pump sets and canal irrigated area.

There are state-specific characteristics that influenced the irrigation financial recovery. Some effects are measurable, while others are not easily observable and hence it is difficult to capture them quantitatively. Given the period covered in the study for 30 years, consistent qualitative information at the state level was not available. Further, the bifurcation of states poses problems in the aggregation of data over time. Given these complexities, we addressed the unobserved heterogeneity (state-level effects) through econometric methods only.

The use of the OLS method to estimate the parameters of research interest produces inconsistent results. This method ignores unobserved heterogeneity that exists across the states and hence error term tends to be correlated within the panel and also between the panel units (Cameron and Trivedi, 2005). Moreover, explanatory variables such as income per hectare are likely to be endogenous. To address these problems, we use a fixed effects estimator to analyse the factors influencing the irrigation financial recovery. The fixed effects estimators are obtained through the mean differencing method, which eliminates the unobserved state-level effects and provides consistent estimates of parameters. Further, this method of estimation also solves the endogeneity problem in the model (Cameron and Trivedi, 2005).

The direction of change of variables is slightly different in the pooled regression model and fixed effects model (Table 8). The estimated fixed effects model, however, provides useful results. The coefficients of agricultural income per hectare, capital stock, and area under rice and wheat were positive and statistically significant. The analysis presented in the previous section did not provide a definite relationship between agricultural income and recovery rate. However, results of the fixed effects model imply that improvement in agricultural income per hectare would enhance recovery of operational expenditure on irrigation projects. Large irrigation capital stock is likely to put pressure on the concerned departments in the respective states to implement institutional measures to recover the cost. The positive and statistically significant coefficients of the area under rice and wheat imply that these crops generate adequate income, which in turn enables farmers to pay the canal water charges.

Financial recovery and irrigation governance

Empirical evidence on the relationship between governance and investment in agriculture and irrigation in India is limited. Kannan, Bathla and Das (2019) developed a robust state-level irrigation governance index (IGI) for 20 major Indian states from 2001-02 to 2015-16 based on 16 indicators using the Principal Component Analysis. The indicators are receipts from public irrigation; rural tele density; rural roads; electricity charges in agriculture; numbers of energized irrigation pump sets; water rate of flow irrigation; revenue and capital expenditure on public irrigation; irrigation potential created under the Accelerated Irrigation Benefit Programme; private (farm households') investment in irrigation; electricity consumption in agriculture; net area irrigated by public canals and tanks; net area irrigated by tube wells and other wells; net area irrigated by sources other than canals, groundwater, tanks and wells; cropping intensity; irrigation potential utilized; and stages of groundwater development. These indicators relate to various economic, social and institutional aspects and are categorised under three dimensions of governance – institutions and regulatory mechanisms; participation and accountability; and service delivery. The empirical analysis shows a positive and significant relationship between irrigation governance and the performance of public irrigation systems, implying a strong need to improve irrigation governance across the states.

Table 9 furnishes the weighted average scores of the irrigation governance index. It is clear that despite increasing outlays on irrigation and initiation of reform measures, the governance index has declined over time from 5.25 in TE 2003-04 to 3.92 in TE 2015-16. Many factors affect governance: a long gestation period in the construction of irrigation infrastructure; environmental constraints; poor maintenance, and low-cost recovery. These problems are aggravated by the ineffective management in the supply and use of irrigation water, which results in the deterioration of irrigation infrastructure, wastage and inequities in water distribution (Vaidyanathan, 1991; Gandhi and Namboodiri, 2009).

Table 8 Factors Influencing Irrigation Financial Recovery: 1983-84 to 2015-16

Variable	Model-1		Model-2	
	Pooled OLS		Fixed Effect Model	
	Coefficient	Std. Error	Coefficient	Std. Error
Dependent Variable: Irrigation financial recovery ratio				
Log Income per hectare	-0.004 (-0.25)	0.0165	0.103* (1.85)	0.0553
Log Capital stock per hectare	0.128*** (7.14)	0.0179	0.164*** (5.48)	0.0298
Log Rainfall	0.050* (1.75)	0.0287	0.078** (2.08)	0.0374
Log Area of rice	0.035** (2.20)	0.0159	0.182** (2.55)	0.0713
Log Area of wheat	0.022*** (4.52)	0.0048	0.051** (2.15)	0.0236
Log Area of sugarcane	-0.057*** (-6.35)	0.0091	-0.137*** (-5.45)	0.0250
Log Irrigation pump set	0.029** (2.85)	0.0102	-0.033 (-0.66)	0.0498
Log Canal irrigated area	0.028* (1.80)	0.0158	0.049 (1.59)	0.031
Constant	-1.99	0.344	-3.96	0.667
R-squared	0.167	0.071		
F	13.82***	12.45***		
No. observations	561	561		

Note ***, ** and * significant at 1 per cent, 5 per cent and 10 per cent; Figures in parenthesis are' t' values

However, large differences in the scores and the ranking of states as per the dimensions of governance are observed. During TE 2015-16, Punjab, Rajasthan, Uttar Pradesh, Madhya Pradesh, and Odisha made significant strides in the development and management of public irrigation systems. The poor performers in IGI were Kerala, Uttarakhand and Bihar. Four states viz. Assam, Jharkhand, Jammu & Kashmir and Himachal Pradesh remained at the bottom, which could be explained by hilly terrain, dependence on rainfall, less public intervention and recurrence of floods. Among major states, Maharashtra, Karnataka, Odisha, Andhra Pradesh and Gujarat had relatively better institutional and regulatory mechanisms compared to other states. From the perspective of participation and accountability, Gujarat, Karnataka, Andhra Pradesh, Maharashtra and Madhya Pradesh held prominence. In the case of the service delivery aspect of governance, Punjab, Rajasthan, Madhya Pradesh, West Bengal and Uttar Pradesh were in the top position.

These results broadly indicate that there is a need to give importance to irrigation institutions that directly or indirectly manage irrigation, improve water use efficiency and thus can help to improve governance for higher agriculture growth. Gandhi (2021) has also found that institutions in the irrigation sector need to be guided, structured and designed through training and support to effectively address the institutional features and management rationalities identified for their success[5].

[5]The study has emphasised on addressing at least three important rationalities, namely, technical (efficient conversion of input to output), organisational (division of labour and coordination) and political (fairness and justice) to improve the performance of irrigation.

Table 9 Irrigation Water Governance Index

State	TE 2003-04	TE 2009-10	TE 2015-16
Andhra Pradesh	5.25	5.12	3.92
Assam	0.91	1.02	1.03
Bihar	3.23	2.94	2.51
Gujarat	5.54	5.00	3.98
Haryana	5.40	5.16	4.35
Himachal Pradesh	0.88	1.46	1.27
Jammu & Kashmir	2.51	1.97	1.46
Karnataka	5.00	4.79	4.11
Kerala	3.78	3.69	2.50
Madhya Pradesh	3.73	4.11	3.71
Maharashtra	5.25	5.36	4.18
Odisha	2.54	3.12	2.64
Punjab	5.05	5.21	4.73
Rajasthan	5.16	5.43	4.36
Tamil Nadu	5.25	5.45	4.10
Uttar Pradesh	4.55	4.70	4.26
West Bengal	2.65	3.01	2.93
Chhattisgarh	2.87	3.32	2.86
Jharkhand	1.68	1.48	1.37
Uttarakhand	2.79	2.20	1.95
All India (20 states) weighted average	4.40	4.57	3.77

Source Kannan et al. (2019).

Key findings and implications

This paper provides estimates of public expenditure on agriculture and irrigation and measures the financial recovery from major, medium and minor irrigation systems in 20 Indian states. The role of governance in improving the performance of public irrigation systems is also discussed. The analysis of public expenditure is carried out at constant (2011-12) prices for the period 1981-82 to 2019-20. The irrigation governance index is computed based on 16 important social, economic and financial indicators collated for each state from 2001-02 to 2015-16.

The analysis shows a sizeable increase in the public expenditure on agriculture and allied activities, major, medium and minor irrigation during the 2000s as compared to the previous two decades. The per-hectare irrigation investment (measured in terms of capital expenditure stock) increased phenomenally between TE 1983-84 and TE 2019-20. Agriculturally advanced states spent relatively more on agriculture and irrigation due to their higher economic growth and hence better spending power. The public expenditure on irrigation has increased in Jharkhand, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal, but these states need to accord high priority to agriculture to accelerate the rate of agriculture growth. Increasing public capital formation (investment) in irrigation has barely corresponded with the outcomes in terms of net irrigated area, potential utilised, and rate of financial recovery. The analysis shows less than 50% of net sown area is irrigated in India and there is stagnancy in the area irrigated by canals and a large gap in irrigation potential created and utilised. It is further seen that canals operate at about 59% technical efficiency, although the level varies widely, from 9.6% in Andhra Pradesh to 100% each in J&K, West Bengal and Madhya Pradesh. Only Rajasthan and Odisha have shown improvement in the efficiency of public irrigation since the 2000s.

The performance of the irrigation system is analysed by estimation of financial recovery in the major, medium and minor irrigation systems separately. The operational expenditure on major-medium irrigation has nearly increased by two times between TE 1985-86 and TE 2019-20. The receipt from major and medium irrigation schemes has also increased during this period. Although an increase in the receipts in absolute value is less than the operational expenditure, the rate of increase in receipts is found to be much higher. Consequently, the recovery rate in the major and medium irrigation projects has improved from 17% in 1985-86 to 33% in 2019-20, although there was a slump in the recovery of expenses during 2003-04. Overall, the recovery rate of major and medium irrigation projects remains low. In the case of minor irrigation projects, the operational expenditure marginally increased between 1985-86 and 2003-04, but it increased steeply thereafter. A rise in operational expenditure indicates the importance given to the development of minor irrigation by the government during the recent decades. However, recovery of the expenses incurred on minor irrigation is also not very encouraging. Despite some improvement in the receipts, a higher proportional rise in the operational expenditure has led to a slow improvement in the financial situation with the recovery rate improving only marginally from 10.35% in 1985-86 to 11.61% in 2019-20. Improvement in the recovery rate and water use efficiency from major-medium and minor irrigation systems is crucial. The results of pooled regression analysis and fixed effects model on the determinants of irrigation financial recovery show a positive effect of agricultural income, capital stock, and area under rice and wheat. Income plays a positive and statistically significant influence in increasing the recovery rate from farmers. Importantly, irrigation governance, which has been low across the states, should be improved and effective to make public expenditure more efficient and enable higher financial recovery from canal and micro irrigation systems.

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Received 25 January 2024 Accepted 4 May 2024

Annexure

Table 1 % of Canal Irrigated Area (CIA) in Net Irrigated Area (NIA) and Net Sown Area (NSA) (four year's averages)

States	% of CIA in NIA		% of CIA in NSA	
	1982-86	2012-16	1982-86	2012-16
Andhra Pradesh & Telangana	49.56	30.91	16.52	13.57
Assam	63.33	25.83	13.44	2.81
Bihar	37.53	31.23	12.53	17.59
Gujarat	19.55	18.21	4.36	7.48
Haryana	54.13	41.12	33.24	35.19
Himachal Pradesh	5.03	3.58	0.82	0.73
Jammu & Kashmir	93.93	87.78	40.47	38.30
Karnataka	41.94	33.75	6.49	11.98
Kerala	37.59	20.83	4.66	4.10
Madhya Pradesh	43.23	17.07	6.42	10.22
Maharashtra	31.64	33.29	3.35	6.23
Odisha	59.73	66.00	15.72	18.54
Punjab	39.76	27.71	34.23	27.62
Rajasthan	33.27	24.70	6.80	10.68
Tamil Nadu	32.96	23.75	14.60	13.58
Uttar Pradesh	33.33	17.90	19.34	15.24
West Bengal	36.94	21.72	13.19	12.86
Chhattisgarh	-	60.60	-	18.90
Jharkhand	-	3.04	-	0.46
Uttarakhand	-	24.67	-	11.66
Bihar- Jharkhand	37.53	29.37	12.53	14.03
Madhya Pradesh -Chhattisgarh	43.23	23.04	6.42	12.24
Uttar Pradesh-Uttarakhand	33.33	18.05	19.34	15.10
All 20 States	36.60	25.94	10.73	12.56

Table 2 Annual Rate of Growth (%) in Public Investment during 1981-82 to 2019-20

States	Public Investment (Agriculture, Irrigation & Flood Control)					
	1981-82 to 1990-91	1991-92 to 2000-01	2000-01 to 2010-11	2011-12 to 2019-20	2001-02 to 2019-20	1981-82 to 2019-20
Andhra Pradesh & Telangana	2.08	1.30	24.01	6.06	8.70	7.89
Assam	-0.10	-1.16	13.82	-5.13	9.65	1.54
Bihar & Jharkhand	-0.12	5.67	8.24	3.10	6.68	2.21
Bihar	-0.12	4.96	10.32	-4.34	5.55	0.53
Gujarat	1.43	9.64	15.32	3.58	9.40	6.42
Haryana	-8.79	19.84	-	-	0.01	0.01
Himachal Pradesh	5.22	4.81	17.96	3.65	5.76	4.92
Jammu &Kashmir	-3.83	-	21.78	-0.90*	10.03*	-
Karnataka	1.83	2.42	7.08	7.86	5.28	6.73
Kerala	-4.31	-0.45	5.09	1.91	5.22	0.47
Madhya Pradesh	1.04	-6.73	12.88	8.52	9.02	3.08
Maharashtra	3.41	2.74	16.30	4.89	3.48	5.65
Madhya Pradesh & Chhattisgarh	1.04	-6.06	13.97	5.78	7.79	4.92
Odisha	-1.57	5.51	8.68	14.46	10.80	3.40
Punjab	-	-	-	-	-	-
Rajasthan	0.95	0.78	3.29	9.55	2.43	1.67
Tamil Nadu	-2.01	10.16	15.70	0.98	6.40	6.01
Uttar Pradesh & Uttarakhand	0.43	13.12	8.37	13.96	5.63	4.36
Uttar Pradesh	0.43	13.06	7.08	15.71	4.75	3.72
West Bengal	3.19	2.82	12.89	19.16	14.78**	5.34
All 20 States	0.40	4.51	12.77	6.23	6.98	5.01

Note '-' not estimated due to negative entries under capital expenditure; *J&Kdata is upto 2018-19 , **West Bengal data upto 2017-18
Source Based on Finance Accounts (GoI)

Agricultural Economics Research Review 2024, 37 (1), 113-122
DOI: 10.5958/0974-0279.2024.00009.6

Export competitiveness of organic food commodities with special reference to Organic Naga King chilli — A revealed comparative advantage approach

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Abstract This paper estimates the competitiveness of India's organic food export in the world markets. Using Compound Annual Growth Rate (CAGR), instability index, trend analysis, Revealed Comparative Advantage (RCA) and forecasting methods, the study has revealed growth in the export of organic wheat, cardamom and Naga king chilli to be positive with an increasing trend, whereas export of organic basmati rice was very low and has shown a declining trend maybe due to the substandard quality of the commodity. Accordingly, the instability in export of organic wheat and organic cardamom has been found to be high due to a rise in their demand in the overseas markets. The study has revealed comparative advantage (RCA) in Naga king chilli export from India with a value of less than unity, which indicated that the share of the Naga king chilli export in the total country's export was negligible. The study suggests that the Export Inspection Council (EIC) of India should strictly monitor the quality testing of the product before it is exported in the global markets so that the price of the product in the international markets becomes highly competitive.

Keywords Organic food commodity, Naga King chilli, instability, Revealed comparative advantage, ARIMA

JEL codes Q17, Q27

Introduction

The organic agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved (FAO, 1999). The organic food industry has experienced a stunning growth during the past few years. The higher disposable income and increasing health awareness have resulted in an increased domestic demand for organic food and there is a huge premium in producing and marketing organic products, not only in the export markets but also to the affluent, health-conscious domestic consumer (Manaloor et al., 2016). The organic trade association reported that sales of organic produce grew by 8.4 per cent in 2016 to US$15.6 billion. About 2.78 Mha of farmland was under organic cultivation in India as of March 2020, according to the Union Ministry of Agriculture and Farmers' Welfare, Government of India. This is two per cent of the 140.1 Mha net sown area in the country (Khurana and Kumar, 2020). The country's exports of organic food products increased by 51 per cent year-on-year to USD 1 billion (Rs 7,078 crore) by 2020-21 and the main goods which recorded healthy growth in exports included oil cake meal, oilseeds, fruit pulps and purees, cereals and millets, spices and condiments, tea, dry fruits, sugar (Economic Times, 2021). India produced 2.67 Mt of certified organic products which included oilseeds, rice, sugarcane, cereals and millets, pulses, fruits, spices, vegetables, dry fruits, tea and coffee (APEDA, 2019). The King chilli (*Capsicum chinense* Jacq.) is an indigenous variety of capsicum specific to the north-east region of India and is known as the hottest chilli in the world. The King Chilli (*C. chinense* Jacq) also called 'Bhut Jolokia' has been placed among the hottest chillies is an indigenous cultivar growing in Nagaland, Manipur and other parts of north-east India. Chilli is a valuable fruit-cum-vegetable all over the world and its production is about 18.8 Mt which is grown on over 1.4 Mha area as fresh and dry chillies in India (Krishna et al., 2007). The king chilli was declared as the hottest chilli of the world by the Defense Research Laboratory, Tezpur, Assam, India, and it has been recorded as the hottest chilli with 1001304 Scoville Heat Unit (Verma et al., 2013). Due to its high pungency and aroma, the king chilli has enormous market potential in both international and domestic markets. The production of king chilli has been reported to increase every year in the north-east India (Meetei et al., 2016). The capsaicin content of king chilli fruits has been found higher in comparison to other chilli species (Sanatombi and Sharma, 2008; Baruah et al., 2014). The Indian organic food industry is rising at an enormous pace. India exports almost all types of organic products and has achieved a tremendous growth in organic exports during 2016-17 to 2020-21 (Deepali and Srivastava, 2021). In north-east India, the foothill conditions with high availability of nitrogen in the region are suitable for the cultivation of an extensive range of capsicum crops, including king chilli (Rongsennungla et al., 2012; Sharma, 2014). By considering its importance, this study reports the growth and pattern of organic food export from India and analyzes the competitiveness of Naga King Chilli export.

Methodology

The present study was entirely based on time series data, taken from the Ministry of Commerce and Industry, Government of India, New Delhi. The data for the cultivating farm areas of organic crops for India as well as north-east region was obtained from APEDA (2020). The data for the export of some organic food commodities which included Naga king chilli, basmati rice, wheat and cardamom was also taken from Ministry of Commerce and Industry, Government of India for the period 2013 to 2021. The harmonized system (HS) code for each commodity was identified to obtain the export data for a specific commodity.

Analytical tools

Estimation of growth rates by exponential trend equation

To study the trends in the export of organic varieties of Naga king chilli, basmati rice, wheat and cardamom, data was analyzed by fitting the exponential function. Accordingly, the Compound Growth Rates (CGR) for the export of these commodities was computed using the following exponential function (Eq.1):

$$Y = ab^t \qquad \ldots(1)$$

Or $\ln Y = \ln a + t \ln b$

The compound growth rate (CGR) was computed by using formula (2):

$$CGR = (\text{Antilog } b - 1) \times 100 \qquad \ldots(2)$$

where,

y = Time series data on export of organic food commodities

b = Regression coefficient, and

t = Time period in years.

Measuring instability

The Cuddy-Della Valle Instability Index (CDI) was used to measure instability in the export growth of organic varieties of Naga king chilli, basmati rice, wheat and cardamom from 2013 to 2021 using the formula (3):

$$CDI = CV \times \sqrt{1 - R^2} \qquad \ldots(3)$$

where,

CV = Coefficient of variation, and

R^2 = Coefficient of determination

And the interpretation of the index was taken as follows:

Low instability: 0-15

Moderate instability: 15-20

High instability: Above 20

Revealed Comparative Advantage (RCA)

In this study, Balassa's (1965) measure of relative export performance by country and industry/ commodity, defined as a country's share in the world exports of a commodity divided by its share in total world exports, was used. The index for country 'i' for commodity 'j' was calculated as per Eq. (4):

$$RCA_{ij} = \left[\frac{X_{ij}/X_{wj}}{X_i/X_w} \right] \quad \text{...(4)}$$

where,

X_{ij} = ith country's export of commodity j,

X_{wj} = Global exports of commodity j,

X_i = Total exports of country I, and

X_w = Total global exports.

If the RCA value is greater than one, then the country is said to have a comparative advantage and if the RCA value is less than one, then the country is said to have a comparative disadvantage.

ARIMA Model

The ARIMA (Autoregressive Integrated Moving Average) popularly called Box–Jenkins (BJ) methodology, is a statistical tool in which the future values are calculated based on the past values of a variable and the random error-terms (Gujarati and Porter, 2009). A general ARIMA model is represented as:

ARIMA (p, d, q).

where,

p = Number of autoregressive terms,

d = Number of times the series has to be differenced before it becomes stationary, and

q = Number of moving average terms.

A generalized ARIMA model is in the form of Equation (5):

$$\Phi\ (B)\ yt = (1–B) – d\ \Psi\ (B)et \quad \text{...(5)}$$

where,

B= Backward shift operator

yt = Actual value at time t.

et = Random error at time t.

Φi (i=1,2,….,p) and Ψj (j=1,2….q) are the model parameters.

The method consists of four steps:

Model identification

At first, we conducted the unit root test for checking the unit root and stationarity of the original data series, because the pre-requisite of the Box Jenkins ARIMA model is that the series should be stationary to estimate the parameter of the model. The Augmented Dickey Fuller (ADF) test was undertaken to find whether the data on export of chilli production was stationary around a mean or had a linear trend or was non-stationary due to a unit root by regression of the equation (6):

$$DY_t = \beta_1 + \beta_2 t + \delta\ Y_{t-1} + \Sigma^{m}_{t=1} \propto t\ \Delta\ Yt - 1 + \in_t \quad \text{...(6)}$$

where,

$\in_t$ = White error-term, and

The number of differences was calculated from Equation (7):

$$\Delta\ Y_{t-1} = (Y_{t-1} - Y_{t-2}) \quad \text{...(7)}$$

The null hypothesis for the ADF test is that H_0: d=0 (there is a unit root) and the alternative hypothesis is that $H_1 = \delta < 0$ (the data is stationary).

The tentative values of p, d and q were worked out with the help of Augmented Dickey-Fuller test and the correlograms of autocorrelation (ACF) and partial autocorrelation (PACF) functions.

Estimation

At this stage, the tentatively chosen parameters of the ARIMA model were estimated based on the Akaike information criterion (AIC) and Bayesian information criterion (BIC) values, given by Equations (8) and (9), respectively:

$$AIC = T \log(\sigma\ 2\ ) + 2(p+q+1) \quad \text{...(8)}$$

$$BIC = T \log(\sigma\ 2\ ) + (p+q+1) \log T \quad \text{... (9)}$$

where,

T = Number of observations used for estimation of parameters, and

δ^2 = Mean square-error.

Diagnostic checking

In diagnostic checking steps, the residuals from the fitted model are examined using the Shapiro-Wilk normality test, given by Equation (10):

$$W=\frac{\left[\sum_{i=x}^{n} aixi\right]^2}{\left(\sum_{i=x}^{n} xi-x\right)^2} \quad \ldots(10)$$

where,

xi = Ordered random sample values, and

ai = Constants generated from the co-variances, variances and means of a normally distributed sample.

Forecasting

At this stage, to evaluate the accuracy of the fitted model, the one step ahead forecasting for the period 2018 to 2022 was done after which the export value was forecasted for a period of five years, from 2023 to 2027. Having being satisfied with the performance of the selected model, the forecasting was done for a period of five years in order to minimize the errors that could arise by increasing the forecasting period.

Results and discussion

Status of organic food products export from India

In the year 2020-21, the exports of organic agricultural products from India grew by 39 per cent to 0.88 Mt, with a value of US$1.04 billion. The United States, European Union (EU), and Canada are the largest export markets for organic food products of India. In 2020-21, the export of organic food products from India to different countries increased considerably — USA (33%), EU (52%) and Canada (7%). India's top organic food products exports (in value-terms) included oilseeds (36%), cereals and millets (26%), and sugar (17%). The goods export volumes exist for spices and condiments (4%) and fodders and teas (both at 3%). India exported in MY 2020/2021 over 660,000 Mt (US$588 million) processed organic food products. The processed organic foods of India constituted largest organic export product category to the United States. Notwithstanding the 2020/2021 COVID-19 pandemic and the national lockdowns that led to the unprecedented marketing and supply chain disruptions.

Table 1 Share of organic area of different north-eastern states in total Ne region (2020-2021)

States	Organic area (in ha)
Sikkim	74647.31
Meghalaya	34816.3
Assam	6719.27
Nagaland	7384.96
Arunachal Pradesh	265.37
Mizoram	40.45
Manipur	4419.25
Tripura	203.56
Total of NER	128496.47
India total	1492611.02
% share of NER to India	8.61

Source Authors' calculations based on APEDA (2020-2021)

India's organic food products exports shot up by 51 per cent in MY 2020/2021 to hit US$1.04 billion mark. The United States was India's key organic product export destination, absorbing 54 per cent of Indian exports. The United States imports Indian organic food products, which reached to US$558 million in MY 2020/2021, up by 58 per cent from the previous year (Agrawal, 2023).

Table 1 depicts the percentages share of total cultivated farm area in different states of North-East region, where Sikkim with 74647.31 ha has the highest organic area compared to other states and Sikkim is considered as the Organic state of India (FAO, 2016). The H S codes for export of four food commodities are mentioned in Table 2.

Table 2 HS code for export of food commodities

Commodities	HS code
Organic Naga King chilli	09042110
Organic Basamati rice	10063020
Organic wheat	11010000
Organic cardamom	09083290

Source Ministry of Commerce and Industry, GoI, 2022

Growth pattern of organic food products export

The compound annual growth rates of some exported organic food commodities from India during 2013 to 2021 are presented in Table 3. It shows that the growth

Table 3 Annual growth trend in export of organic food commodities from India: 2013-2021

Commodities	CAGR (%)
Organic Naga King chilli	20.29
Organic Basmati rice	1.45
Organic wheat	7.07
Organic cardamom	20.32

Source Authors' calculations based on the export data from Ministry of Commerce and Industry, GoI, New Delhi, 2022

rate of organic cardamom export was highest (20.32%), followed by organic Naga king chilli (20.29%) and organic wheat with (7.07%). However, the CAGR of organic basmati rice export was found very low with (1.45%) maybe due to the drastic fall in the export during the COVID-19. Sudha and Sharath (2022) have reported that the export of six key agricultural products, including tea, spices and tobacco, has registered a negative growth in 2014-15 mainly due to a decline in their prices in global markets. Contraction in the export of these commodities was one of the reasons for a decline in the country's total exports in 2014-15. A similar study by Agrawal, (2021) has reported that the rice export from India dropped due to uneven rainfall in the country and due to which the domestic production of rice suffered. However, the total Indian export (merchandise and services combined) stands at the positive growth rate of 6.57 per cent. Rao and Prasad (2018) have revealed a significant growth in production (1872010 Mt) and exports (400250 Mt) during 2016-17. India has considerable potential for development in area, production and exports of Chillies.

The instability index for the export of various food commodities is presented in Table 4, which shows that organic Naga King chilli and Basmati rice had a low instability index of export with 8.06 and 13.39 values. On the other hand, organic wheat and cardamom had shown a high instability index in the export with index of 40.02 and 34.82, respectively, as the export of both wheat and cardamom had drastically increased from 2020 and 2021. However, Nair (2006) has reported that the instability in export quantity has declined significantly. Considering the trade potential and demand for cardamom, the crop is expected to retain commercial significance in the coming years.

Table 4 Estimated instability index for export of organic food commodities from India

Commodities	CV	R^2	Ix
Organic Naga King chilli	47.42	0.91	8.06
Organic Basmati rice	13.43	-0.05	13.39
Organic wheat	42.57	0.24	40.02
Organic cardamom	60.04	0.65	34.82

Note Authors calculations based on the export data from Ministry of Commerce and Industry, GoI, New Delhi, 2022

The trends in the export of four organic food commodities in value terms have been presented in Figures 1-4 for the period 2012-2022. The trend analysis of the export of Naga king chilli (Figure 1) shows an increasing growth over the years which indicates its potential for export. The trend analysis of organic basmati rice (Figure 2) shows that its export was variable during the study period. Its export has decreased over the years which might be due to reasons like poor quality of the product, impact of COVID-19 pandemic and uneven rainfall in the area during the harvesting seasons. The export trend analysis of organic wheat from India indicates a positive growth over time and especially during 2020 and 2021. The demand for the Indian organic wheat in the overseas market (Figure 3) has increased tremendously resulting in a sharp increase in its export during 2020 and 2021. The trend

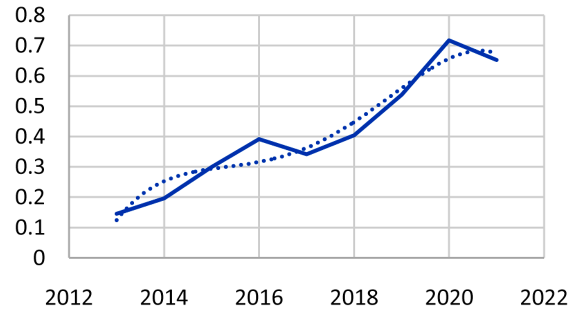

Figure 1 Trend analysis for Naga King chilli export

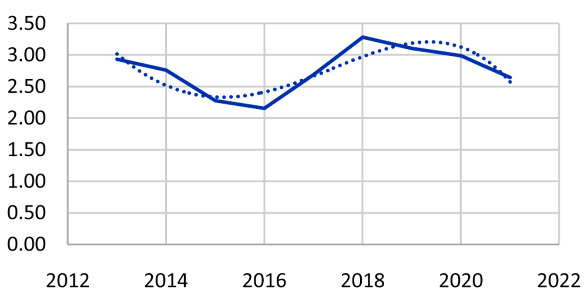

Figure 2 Trend analysis for basmati rice export

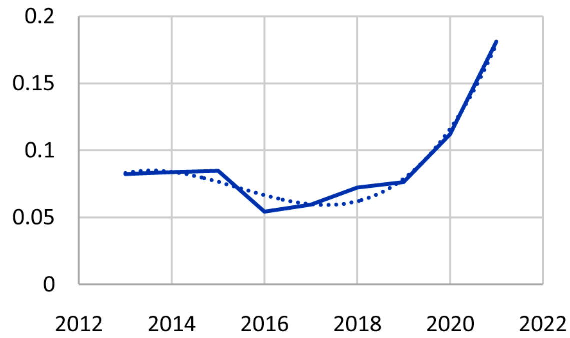

Figure 3 Trend analysis for wheat export

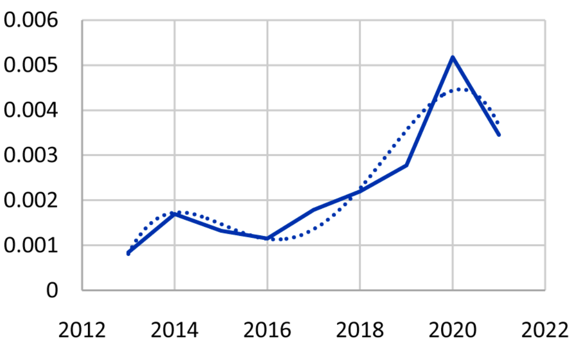

Figure 4 Trend analysis for cardamom export

analysis of the export of organic cardamom (Figure 4) shows an increasing and positive growth trend over the years except during 2021.

The percentage share of four major organic food commodities in total Indian export is shown in Table 5. The percentage share of Naga king chilli export in total Indian export has been very low throughout the study period, though it shows an increasing trend from 0.076 per cent to 0.207. Similarly, the percentage shares of organic wheat and cardamom have been very small in total Indian export though Table 5 shows an increasing share over the years (0.043% to 0.57% for wheat) (0.00044% to 0.0011% for cardamom) during 2013-2021. The organic basmati rice has shown a higher export percentage share compared to other commodities, but it decreased over time from 1.537 per cent to 0.838 per cent in the total Indian export.

The revealed comparative advantage of Naga king chilli export for the period 2013-2021 has been presented country-wise in Table 6. It shows that RCA for export of Naga King chilli to Bangladesh has been highly unstable over the years, but has maintained a

Table 6 Revealed Comparative Advantage (RCA) of Naga King Chilli export from India: 2013-2021

Year	Bangladesh	China	Indonesia	Malaysia	Sri Lanka	Thailand	UAE	USA	Vietnam
2013	1.51	0.19	2.94	9.66	7.13	15.36	0.01	0.15	8.07
2014	0.87	0.15	2.54	5.91	5.15	14.44	0.01	0.13	9.98
2015	0.96	0.15	4.37	6.72	6.04	14.75	0.01	0.14	9.42
2016	1.70	0.11	5.31	4.14	6.75	11.92	0.02	0.09	9.70
2017	0.81	0.46	3.87	3.11	4.62	9.65	0.02	0.15	12.64
2018	0.95	3.24	3.76	2.88	5.71	9.65	0.02	0.13	7.81
2019	2.21	5.48	4.19	2.54	6.83	8.60	0.02	0.12	1.11
2020	2.35	4.34	2.82	2.04	5.71	6.68	0.21	0.11	0.81
2021	1.36	6.82	2.63	2.72	5.49	6.21	0.06	0.17	0.37

Source Authors' calculations based on data from Ministry of Ministry of Commerce and Industry, GoI, New Delhi, 2022

Table 5 Percentage share of some organic food commodities in total Indian export: 2013-2021

Food Commodity	2013	2014	2015	2016	2017	2018	2019	2020	2021
Naga chilli	0.076	0.103	0.174	0.211	0.174	0.175	0.242	0.332	0.207
Basmati rice	1.537	1.454	1.323	1.163	1.373	1.421	1.397	1.382	0.838
Wheat	0.043	0.044	0.049	0.029	0.030	0.031	0.034	0.052	0.057
Cardamom	0.00044	0.00090	0.00077	0.00062	0.00091	0.0009	0.0013	0.0023	0.0011

Source Authors' calculations based on data from Ministry of Commerce and Industry, GoI, New Delhi, 2022.

comparative advantage during the past three years. The export of king chilli to China had a low comparative disadvantage during the period 2013-2017, but from 2018 China has increased the share of Naga king chilli import which has given it a higher comparative advantage. The export to Vietnam's had a high comparative advantage from 2013 to 2019 but after COVID-19 pandemic, there has been a decrease in comparative disadvantage rate from 2019 onwards. The exports to Indonesia, Malaysia, Sri Lanka and Thailand have revealed a high value of comparative advantage at the import of Naga king chilli during the study period (2013-2021). The UAE and USA have shown a low value of comparative disadvantage in the export of Naga king chilli from India.

India's competitiveness in cardamom exports was deteriorating gradually from the early 1990s and continued till 2010, reported by Thomas et al. (2019). The unit export value of cardamom from India has consistently remained higher than that of the competing countries. The period of declining RCA for Indian cardamom coincides with a spectacular rise in its production in other major competing countries like Guatemala. Therefore, unless a supply shock occurs in the competing economies or the global demand significantly outpaces global supply, the Indian cardamom exports could remain less competitive than that of its competitors like Guatemala and Indonesia.

The correlograms of ACF (Autocorrelation function) (Figure 5) predict that Naga king chilli has a great potential for export in the near future. A study conducted by Mendhe and Degaonkar (2010) using Markov chain analysis has revealed a huge scope to expand the export of chilli to Malaysia, Sri Lanka, Singapore, USA, UK and other countries. The farmers of north-east should be encouraged to cultivate it for higher returns and better economic status.

Analysis of ARIMA

The p-value of the ADF test statistics for the export of chilli has been found higher than 0.05 (Table 7) which implies that the original series has a unit root. Therefore, the series is non-stationary at this level. To get a stationary series, we need to go for differencing the series so that there are no unit roots. Finally after performing one differencing, we can see from Table 7 that p-value for ADF test is 0.01, which is less than 0.05. The Dickey-Fuller Statistic (τ) is significant at the 10 per cent level and is higher than the critical value after just the first differencing and ultimately the time series becomes stationary (Table 7).

Table 7 ADF test for stationarity of the model

Order of the model	Dickey-Fuller Statistic	p-value
0	- 1.1475	0.89
1	- 7.499	0.01

Source Computed by authors using R (4.0.2) software

The time series data of chilli export was plotted to identify any unusual observations. For this study, data for the past 10 years was used for the modelling of chilli export from India. The PACF plot of the data was used to identify the AR order and the ACF plot was used to identify the MA order of the ARIMA process. Figure 5 and Figure 6 show the plots of autocorrelation function (ACF) and the partial autocorrelation function (PACF), respectively and these give a specific pattern about the autoregressive and

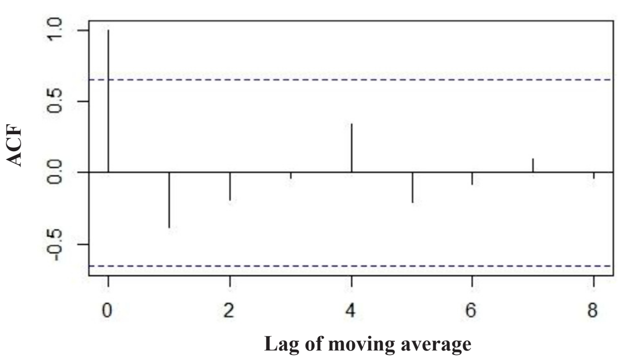

Figure 5 Correlogram of Autocorrelation Function (ACF)

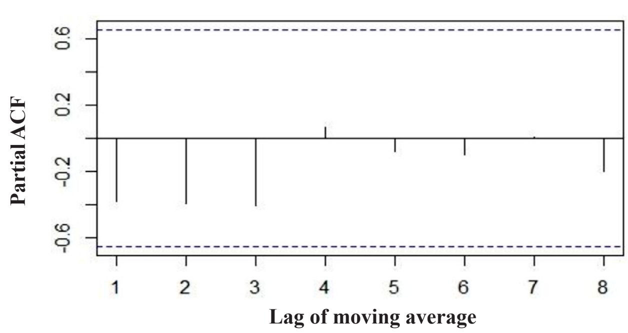

Figure 6 Correlogram of Partial Autocorrelation Function (PACF)

moving average orders. The 2nd differenced series of export of chilli has revealed that there is no exponential decay in both ACF and in PACF plots, indicating the AR (0) and MA (0) terms. Therefore, it confirms that for export of chilli from India, the possible AR order might be 0 and MA order be 0 (Figures 5 and 6).

Model estimations

The values of Akaike Information Criterion (AIC), and Baye Information Criterion (BIC) were used for selecting the values of p, d and q because it implies that the model with minimum AIC and BIC values is closer to the best possible choice as they have residuals with white noise. Table 8 reveals that for chilli export ARIMA (0, 1, 0) was the best model based on the values of AIC and BIC and it would help in subsequent modelling and forecasting of the export of chilli from India.

Table 8 Estimation of ARIMA model with AIC and BIC

ARIMA (p, d, q)	Akaike information criterion (AIC)	Bayesian information criterion (BIC)
(0, 1, 0)	142.92	136.13

Source Computed by authors using R (4.0.2) software

Diagnostic checking

To find the validity of the ARIMA (0,1,0) model, the residuals are tested for normality with the help of Shapiro Wilk test. It is a test of normality for small sample sizes (n <50). The null hypothesis for this test is that the data are normally distributed. If the chosen alpha level is 0.05 and the p-value is less than 0.05, then the null hypothesis that the data are normally distributed is rejected. If the p-value is greater than 0.05, then the null hypothesis is not rejected. Table 9 shows that the data has normal distribution with W statistic of 0.98 and p-value of 0.96. Ultimately, the test of the residuals for the fitted ARIMA (0, 1, 0) model suggests that there is no significant pattern in the residuals and hence, it may be concluded that the residuals are normally distributed and the model is suitable for predicting the export of chilli as there is no autocorrelation among the residuals of the model.

Table 9 Test for normality of the residuals

Particulars	Value
W	0.98
p-value	0.96

Source Computed by authors using R (4.0.2) software

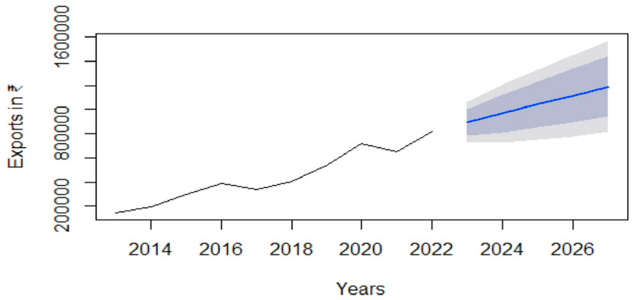

Figure 7 ARIMA (0,1,0) forecast of organic Naga King chilli export by 2027

Forecasting using ARIMA model

The ARIMA (0, 1, 0) model was used for comparing the actual and predicted values of export of chilli for the years 2018 to 2022 for further validation of the model. Figure 7 depicts the forecast plot for the export of chilli from India. From Figure 7 we can see that after 2022, the forecast from the given data is presented with the highest and the lowest estimates at 80 per cent and 95 per cent of confidence interval. The plot clearly shows an increasing picture of the export of chilli from the country by 2027. This is quite evidently depicted in Table 10 too. It can be noted that most of the predicted values shows increasing values with the actual values. It is again evident that the highest and lowest predicted values for 2027 at 80 per cent confidence interval were 945064 Mt and 1437947 Mt and at 95 per cent confidence interval these were 814606 Mt and 1568405 Mt, respectively. A similar trend in increasing export of chilli from India was reported by Chaitra and Sonnad (2019) and Ashoka et al. (2013). This is expected to provide an impetus to the chilli growers of the country to adopt more area under chilli and make the use of the improved varieties with proper scientific intervention. Besides, it would boost foreign exchange revenue of the country and will put India at a higher position in chilli export.

Conclusions

The study shows that annual trend in export of organic food commodities from India had a positive growth over time. The organic Naga king chilli grown in the

Table 10 Export forecast of chilli from India for the fitted ARIMA (0, 1, 0) (in metric tonnes)

Year	Actual value	Predicted value	Lo 80	Hi 80	Lo 95	Hi 95
2018	404773					
2019	537440					
2020	717015					
2021	652815					
2022	817993					
2023	-	892695	782484	1002908	724141	1061250
2024	-	967398	811535	1123261	729026	1205770
2025	-	1042100	851208	1232993	750155	1334046
2026	-	1116803	896379	1337227	779694	1453912
2027	-	1191505	945064	1437947	814606	1568405

Note Lo = Lower bounds, Ho= Upper bounds
Source Computed by authors using R (4.0.2) software

north-east states constitutes about 20.29 per cent growth along with low instability in the export performance, which indicates its market potential and profitable enterprise for the farmers. However, the RCA has revealed that, India had a comparative disadvantage vis-a-vis other countries in the export of Naga king chilli as its domestic price appears to be higher compared to international market prices. In addition, the product standards may be unsatisfactory according to the international quality standards of product. On the other hand, the ARIMA forecasting of king chilli export has indicated an increasing growth over the year, which indicates a great potential in future.

The study has stressed that to boost the export of Naga king chilli from India, the Export Inspection Council (EIC) should strictly monitor the quality testing of the product before it is exported to the global markets so that its price in the international market becomes highly competitive. The export share of Naga King chilli in the total export of country would increase when the exporters get the premium price, thereby leading to an improvement in the export competitiveness with other rival countries.

Acknowledgement

The study was a part of the Ph. D. research work and the authors gratefully acknowledge the Central Agricultural University (Imphal), for facilitating and supporting this work throughout the research period. They thank the Ministry of Tribal Affairs, Government of India, for providing funding support to this research through the National Fellowship for Scheduled Tribes (NFST).

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Received 6 November 2023 Accepted 27 March 2024

Agricultural Economics Research Review 2024, 37 (1), 123-132
DOI: 10.5958/0974-0279.2024.00003.8

Increasing the fruit growers' share in the marketing system

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Abstract The growers' share in consumer rupee is an essential part of agricultural marketing that assures the supply chain's long-term viability and profitability. This study determines the apple growers' share in final pricing by evaluating the efficacy of marketing channels predominant in the Kashmir valley, India. The composite index technique has been used to assess the marketing efficiency. The study is based on the interviews of 390 growers, 100 commission agents, 30 wholesalers, 20 contractors, and 20 retailers. The survey identified six apple marketing channels in the study area and has reported most profitable and least profitable channels. By adoption of more efficient marketing channels and marketing strategies, the growers can improve their profitability. The study has suggested that, improvements in the local infrastructure for fruit marketing, better access to market information, and extension of cold storage facilities in the study area would contribute significantly to farmer's income.

Keywords Growers' share, apple marketing, marketing channels, infrastructure development, Kashmir valley

JEL codes Q11, Q13, Q18

Introduction

The growers' share in horticultural marketing is significant because it has a direct impact on the income and profitability of farmers (Fan and Salas Garcia, 2018). This can lead to increased financial stability and sustainability for the farmers, allowing them to invest in their operations and improve the quality and quantity of their produce (Kohl and Uhl, 2002; Paul et al., 2020). A higher growers' share can also lead to better prices for consumers. Growers' share plays a crucial role in the success and viability of the horticultural segment, where government intervention is minimal on account of price fixation and procurement, as is the case in cereals (Romero Granja and Wollni, 2018).

In India, the small landholders often need help regarding access to markets, appropriate infrastructure and credit facilities, which make them vulnerable to exploitation by the intermediaries (Acharya, 2004; Kamble, 2019). The horticultural sector is characterized by a high degree of fragmentation, with smallholder farmers accounting for a large share in production and receiving a smaller share in the marketing chain (Bhutta et al., 2019; Vadivelu and Kiran, 2013). These farmers often need capacity to negotiate better price for their produce and have access to more profitable market channels (Agarwal et al., 2019; Lutsiak et al., 2020). The studies show that small farmers receive a much lower share in the final price that the consumer pays for the produce, which makes it difficult for them to make a living (Mgale and Yunxian, 2020; Selvaraj et al., 2012). Improving growers' share can make this sector more profitable and sustainable, thereby contributing to economic development in the rural areas (Mmbando et al., 2015). An effective horticultural product marketing can help the farmers in receiving a better product price and increase their profits (Chand et al., 2020; Girmay et al., 2014). It can also create a stable and predictable market for horticultural products, attracting more investment into the sector. The effective marketing helps to make sure that farmers get a fair price for their crops, and it also helps to ensure that consumers have access to a wide variety of fresh, high-quality fruits and vegetables (Das et al., 2014; Dastagiri et al., 2012).

The marketing channels in the horticultural commodities are often complex and include several intermediaries, such as wholesalers, retailers, and distributors, each adding to the cost and time of getting products and reach to the customers (Singh, 2012). The efficiency of horticultural market channels refers to the ability of various intermediaries and distribution channels in the chain to connect growers with consumers while minimizing costs effectively, reducing wastages and maximizing the value of products (Kalita, 2017). A well-designed marketing strategy can help growers reach the appropriate target market, reduce food wastage and increase the final product price. It also allows them to plan their production and target the right time to sell their products to fetch a better price (Fafchamps et al., 2005; Paul et al., 2020).

In Jammu and Kashmir, the horticultural sector is an important source of income for farmers. However, like in other parts of India, small farmers face several challenges regarding access to markets and appropriate infrastructure, which can lead to their lower share (Rashid et al., 2023) . Apple which is the main fruit grown in the region, shows that the growers often receive a low share in the final price due to high degree of intermediation in the market and inadequate storage and transportation infrastructure (Shah and Songara, 2019) .This makes it more challenging for farmers to earn a living and reinvest in their fields (Hassan et al., 2021; Wani et al., 2021). Several factors can affect the growers' share in marketing are type of product, target market, supply chain, bargaining power of grower, and government policies. The different marketing channels also influence the growers' share.

For this study, the Kashmir Valley was chosen as its economy is based on agriculture, horticulture and tourism (Hajam et al., 2024; Husain, 2000; Jeelani et al., 2022). Agriculture is the main source of livelihood for the majority of population in the valley (Hajam et al., 2023). The valley's cool temperate climate, ample rainfall, and fertile soils make it well-suited for growing a wide variety of fruits and vegetables (Kutumbale and Eytoo, 2019). Some of the most important crops grown in the valley include apples, apricots, peaches, plums, walnuts, almonds, cherries, and saffron. Apple is the most important crop grown in the valley and contributes a large portion to the horticultural production in the region (Zaffar and Sultan, 2019). It is a significant source of income for the people and a major source of state's GDP. Presently, Kashmir Valley has an area of 213800 ha under horticultural crops and produces 1989700 Mt of fruits annually. Apple being the dominant crop has an area of 148900 ha and produced 1695000 Mt in 2022 (Directorate of Horticulture, Kashmir 2022). In the valley, apples are mainly grown on traditional orchards, which are mostly owned and operated by small farmers (Lone et al., 2022). The traditional orchards are characterized by traditional farming such as the use of local varieties, organic farming methods, and minimal use of chemical pesticides (Ganaie et al., 2022). The traditional orchards are also known for their biodiversity, as they often include a variety of other fruits and vegetables, as well as livestock.

A study on increasing growers' share in final price can suggest ways to improve the economic situation of apple growers, which can boost regional economic growth (Naqash et al., 2017; Wani et al., 2021). The study aims to fill this void by analysing the efficiency of prevailing marketing channels in apple. It has three main objectives: (1) to identify the different apple marketing channels in the study region, (2) to measure the efficiency of identified market channels; and (3) to compare the shares received by the growers' in the final price across the identified market channels.

Materials and methods

The study gathered primary data from apple growers and other stakeholders through a pre-structured questionnaire and interviews. The questionnaires were subjected to a reliability and validity test before distribution. The number of respondents (apple growers) selected for the study were 390 (using Cochran sampling method) from the eight major apple producing districts, Baramulla, Shopian, Pulwama, Kupwara, Anantnag, Kulgam, Budgam and Ganderbal in the Kashmir Valley (Fig. 1). For the study, 100 commission agents/auctioneers, 30 wholesalers, 20 contractors and 20 retailers were also selected. The field surveys were conducted to identify the prevalent apple marketing channels involving growers directly. A field survey of growers can provide valuable insights into the market channels that are highly effective for reaching this group of stakeholders (Ali and Kachroo, 2020; Zivenge and Karavina, 2012). The data on marketing costs, average prices, and marketing margins were collected to analyse the cost-effectiveness of various marketing channels in apple.

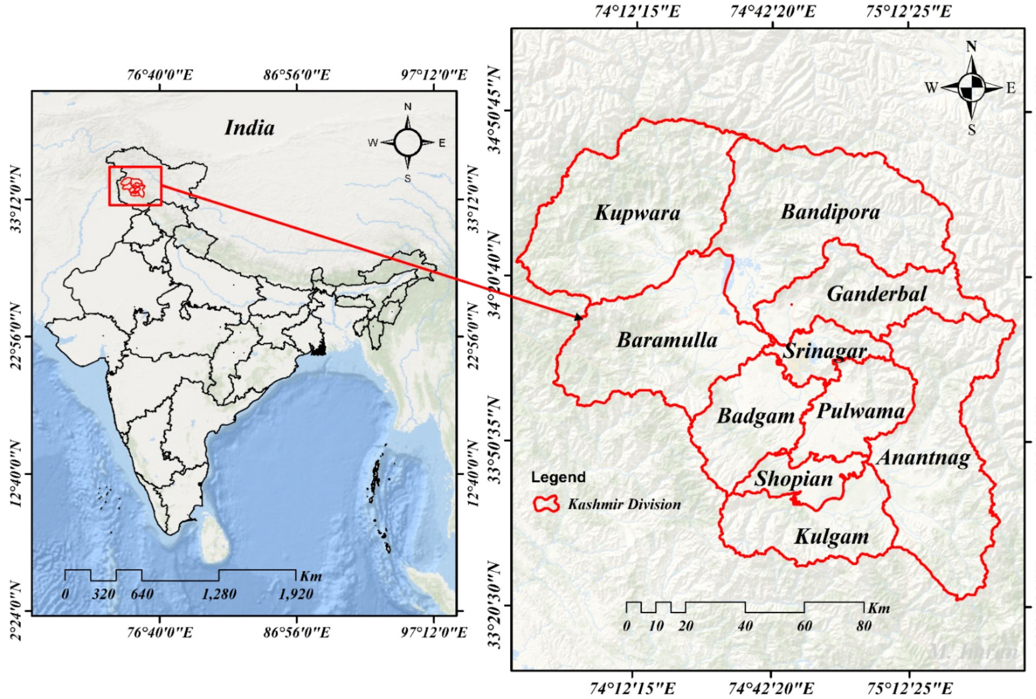

Figure 1 Location map of the study area

The study adopted (Acharya and Agarwal, 2016) model for analysing the efficiency of different marketing channels (Mgale and Yunxian, 2020). The models used are:

$$Gs = \frac{Gp}{Cp} \times 100 \qquad \ldots(1)$$

$$Ps = Cp - Fp \qquad \ldots(2)$$

$$\mathrm{ME} = \frac{NPp}{TMC + TMM} \qquad \ldots(3)$$

$$MEI = \frac{Ri}{Ni} \qquad \ldots(4)$$

where *Gp* denotes the producers' price, Cp denotes the consumer's price (the value of commodities purchased), *Gs* denotes the growers' share, and *Ps* denotes the price spread between growers' price and ultimate consumers' price. In Acharya's method, *ME* is marketing efficiency, *NPp* is the net selling price of growers (selling price including marketing expenses), *TMC* is the total marketing cost of intermediaries, and *TMM* is the total marketing margin. *MEI* is the composite market efficiency index, *Ri* is the sum of ranks in each channel, and *Ni* is the total number of performance indicators.

The marketing costs were determined were determined by aggregating the expenses incurred by each marketing activity in the apple distribution chain for their marketing operations. Due to difference in the quality of apple, marketing locations, types of marketing institutions, and marketing activity, marketing expenses vary by channels (Acharya and Agarwal, 2016). The marketing costs involve costs incurred on the movement of products from the Producers to the ultimate Consumers, e.g. costs of packaging, harvesting, loading, unloading, weighing, transport, and storage. The marketing margins involve profits of the various market functionaries involved in moving the product from the initial point of production to the ultimate consumer. It is calculated by subtracting the cost price (buyer price and marketing cost) from the selling price of apple fruit (Gangwar et al., 2014). The size of marketing margins in various apple marketing channels depends on the length of channels, the number of economic actions that occur during marketing activities, and the estimated profit margins of each marketing institution involved (Panda and Sreekumar, 2012). In addition, the price spread was determined by subtracting the growers' net price from the retail sale price/consumer price.

Analysis of Variance

To compare the mean efficiency scores of the channels one way ANOVA was used with the following hypothesis:

H0: The mean marketing efficiencies of the channels are exactly equal.

The alternative hypothesis, as already mentioned is,

H1: The mean marketing efficiencies of the channels are significantly different.

The F statistics for ANOVA is:

F = between group variability / within group variability

Thus, the model used was:

$$F = \frac{SS_R/k-1}{SS_E/n-k} = \frac{\sum_{i=1}^{n}(\hat{y}-\bar{y})\,/k-1}{\sum_{i=1}^{n}(y-\hat{y}_i)\,/n-k}$$

k is the number of parameters and n is the number of observations.

Results and discussions

Identification of market channels

The Identification of marketing channels is critical because it helps the fruit growers to understand where their target customers are and how to reach them effectively. The marketing process begins with the growers and ends with the consumers. Between these two extremes, various intermediaries, viz. contractors, commission agents, wholesalers, retailers, etc. perform their roles for the marketing channel to be completed (Murthy et al., 2009). The market channels refer to the various ways in which fruits can be sold, such as directly to consumers, through wholesalers or distributors, or through retailers (Pham et al., 2019). In the study region, apple production is spread throughout the region, and the fruit is commercial. Through an extensive survey, the study identified six apple market channels in the region through which growers sell their produce. The brief description of the identified market channels is given below:

Channel 1: Selling produce (apples) from trees to local buyers without harvesting themselves. This channel is one of the oldest, where the grower takes money from the contractor before harvesting the produce, and the contractor does all further processes. According to the survey, 9.1% of the apple growers were following this channel of fruit marketing.

Channel 2: The fruit growers were selling their produce to local buyer without proper packing after harvesting. This channel differs from the former as the growers themselves harvest the fruit and then local buyer carry the further marketing process. This channel has also been prominent in the study region, and as per the survey, 9.3% of the apple growers follow this channel of apple marketing.

Channel 3: In this channel, the growers harvest and properly pack their produce before marketing. This channel differs from the previous one only in packaging the produce. This channel is quite prominent in the study area. As per the survey, 16.2% of apple growers used this marketing channel.

Channel 4: Selling of fruits by growers to local fruit market centres in the study region. This channel has witnessed a tremendous increase in the last decade, largely because of the establishment of new fruit markets in the study region (Rashid et al., 2022). The study region has ten operational fruit market centres, and most of them have been functional for the last decade. According to the survey, 34.7% of the apple growers were following this channel of fruit marketing.

Channel 5: In this channel, the growers sell their produce directly to national fruit mandis, usually in Delhi, Agra, Mumbai, and Bangalore. This mode of fruit marketing gained popularity in the study region in the last three decades with the better transport network and road connectivity. Moreover, the local growers developed direct contacts with commission agents and wholesalers working in these market centres, which led to an increase in the supply chain of the produce. As per the survey, 17.3% of apple growers used this marketing channel.

Channel 6: Besides all the Apple market channels, the study region has one more mode of Apple marketing: cold stores. Some growers keep their produce in controlled atmosphere (CA) storage established in the study region for reasonable prices during the off-season months of March and April. About 10% of the total produce (20 lakh metric tonnes) of Kashmir apple is stored in cold storage units located mainly in Lassipora (Pulwama), Aglar (Shopian), and in some areas of Srinagar and Anantnag. This channel has recently

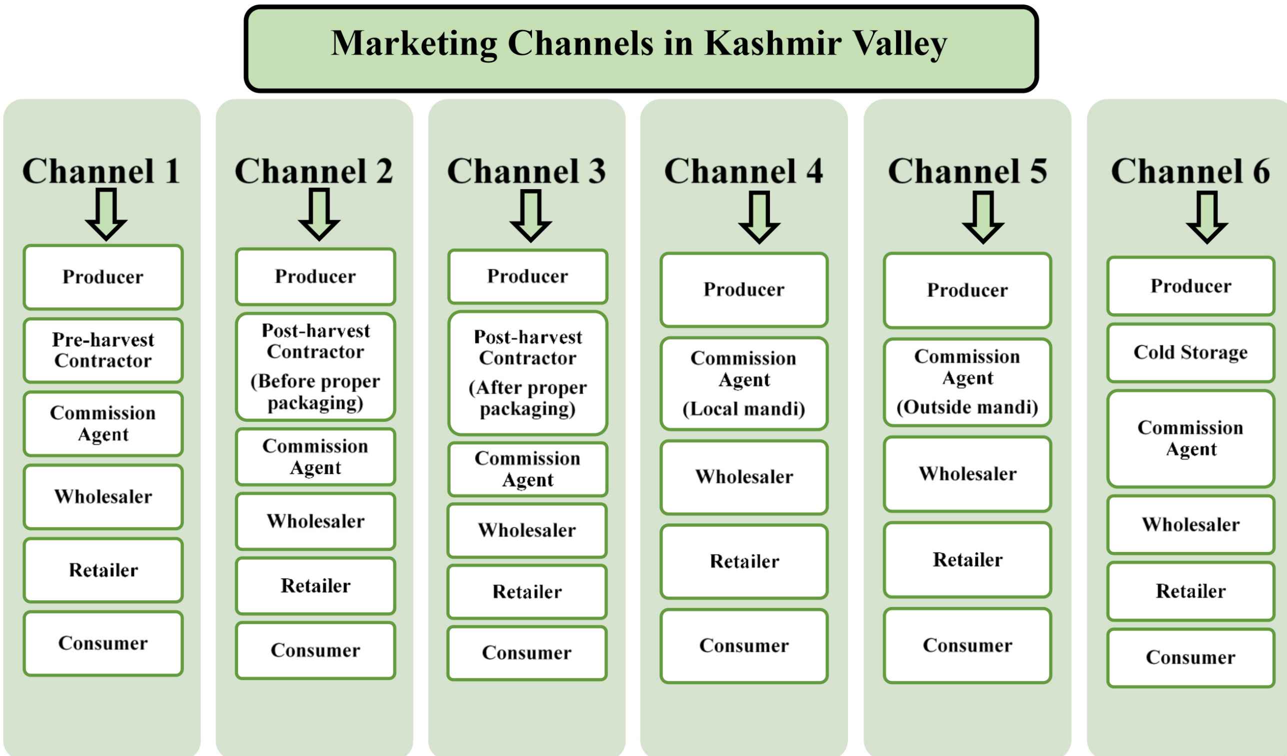

Figure 2 Representation of major apple marketing channels in the study region
Source Field survey; 2020, 2021 and 2022

gained massive popularity because of lesser market competition in off-seasons, often leading to higher produce prices. According to the survey, 11.2% of apple growers were following this channel of fruit marketing.

For clear illustration, all the identified apple market channels prevalent in the study region are shown in Figure 2 and Table 1 shows the share of apple marketed through each market channel.

Table 1 Share of fruit (apple) marketed through different market channels

Type of Channel	Share (%)
Channel 1	9.1
Channel 2	9.3
Channel 3	16.2
Channel 4	34.7
Channel 5	17.3
Channel 6	11.2
Others	3.2
Total	100

Source Field survey; 2020, 2021 and 2022.

Indicators of marketing efficiency

The marketing costs, farmers' share of consumer price and margins for each of the six apple marketing channels are shown in Tables 2 and 3. The figures were based on information obtained from the growers and traders regarding prices and operational expenses. Table 2 reveals that channel 6 had the highest marketing cost followed by channel 1, whereas channel 4 had the lowest cost. The costs associated with marketing include, packaging, processing, storage, transportation, taxes and fees. Many marketing intermediaries, including growers, contractors, commission agents, traders, wholesalers, and retailers, contributed to the high marketing expenses in channel 1; this indicates that the longer the apple marketing channel, higher is the consumer price. The proportion of marketing margin incurred by marketing agencies in each marketing channel revealed that channel 1 incurred the highest proportion of expenses, while channel 6 incurred the least (Table 2). In distribution under channel 1, the product is moved from the grower to consumer through maximum intermediaries. The increase in the number of intermediaries proportionally increases the total cost of this marketing channel. Accordingly, the marketing channel with the most extended length, channel 1, has the widest price spread (Tables 2 and 3). This indicated that the marketing intermediaries took advantage of the costs invested to get a larger profit share than other channels. While channel 6 and channel 4 had the lowest pricing differential, as there are fewer intermediaries participating in these channels. According to (Wohlgenant and Mullen, 1987), the smaller is the marketing channel's price spread, more efficient it is for growers, and vice versa.

The growers' share is one of the quantitative assessment instruments for evaluating the marketing efficiency, indicating that higher the share, more efficient the channel is from the growers' standpoint. Although, in practice, growers do not care about the proportion of the consumer price they receive, as their concern centres around fluctuations in price. Table 3 shows that channel 6 is the most effective among all six apple marketing channels. The growers' share is maximum in channel 6 because of fewer intermediaries, which also demonstrates effectiveness of the supply chain. Also, the producer share is the smallest in marketing channel 1 because it lasts longer than other marketing channels.

Table 2 Price spread of apple box (weighing about 18-20 kgs) in each prevalent marketing channel (in Rs)

Particulars	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6
Producer/Grower						
Price received by grower	430	480	620	750	864	1130
Marketing cost incurred by farmer	0	20	105	185	250	420
Net profit for farmer	430	460	515	565	614	710
Local Buyer						
Price received by local buyer	750	765	800	-	-	-
Price paid by local buyer	430	480	620	-	-	-
Marketing cost incurred by local buyer	255	235	150	-	-	-
Net profit for local buyer(Margin)	65	50	30	-	-	-
Commission Agent						
Price received by commission agent	825	845	877	820	940	1200
Price paid by commission agent	750	765	800	750	864	1130
Marketing cost incurred by the commission agent	16	16	16	16	21	17
Commission charges gained by the commission agent	70	70	70	70	70	80
Net profit for the commission agent (margin)	129	134	131	124	125	133
Wholesaler						
Price received by the wholesaler	1010	1034	1061	1012	1048	1290
Price paid by wholesaler	825	845	877	820	940	1200
Marketing cost incurred by wholesaler	135	135	135	135	60	60
Net profit gained by wholesaler (Margin)	50	54	49	57	48	30
Retailer						
Price received by retailer	1132	1145	1178	1120	1169	1380
Price paid by retailer	1010	1034	1061	1012	1048	1290
Marketing cost incurred by retailer	22	22	22	22	22	25
Net profit gained by retailer (Margin)	100	89	95	86	99	65
Consumer						
Price paid by consumer	1132	1145	1178	1120	1169	1380

Source Computed by the authors based on survey

Table 3 Marketing efficiency of different apple marketing channels (Rs/box)

Particulars	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6
Price received by Grower	430	460	515	565	595	765
Marketing cost	428	428	428	358	353	467
Marketing Margin	264.5	243.7	266.6	192.2	203.4	167
Marketing Efficiency	0.62	0.69	0.79	1.03	1.07	1.15
Consumer price	1132	1145	1178	1120	1169	1380
Price spread	702	685	663	555	604	615
Share of grower in consumer's Price	37.98	40.17	43.72	50.45	50.90	55.5

Source Compiled by authors based on field survey

Marketing efficiency of different market channels (Acharya and Agarwal 2016 model)

The model developed by Acharya and Agarwal (2016) was used to measure the cost–benefit efficiency of apple marketing channels based on the ratio of growers' selling price to marketing costs and marketing margins (Eq. 3). According to this model, a higher value indicates a higher level of marketing efficiency and vice versa. Table 3 revealed that channel 6 had the highest efficiency value (1.15), indicating it to be the most efficient channel, followed by channel 5 and 4 with values of 1.07 and 1.03 respectively. In contrast, channel 1 has the lowest efficiency value (0.62). As per the analysis, the channels 6, 5, and 4 turned out to be highly efficient due to the higher prices received by growers and the lower marketing costs incurred by intermediaries, as compared to channels 1, 2 and 3. Similar results have been observed in the studies of (Aguinaldo et al., 2014; Chaudhary et al., 2016; Gandhi and Namboodiri, 2005; Kalita, 2017; Sonia et al., 2016).

Composite score method

For calculating composite index of apple marketing channels for apple, a comparative analysis was undertaken using [Equation 4]. Table 4 shows that the ranks were allocated based on the following criteria: a higher rank (with 1 being the highest rank) for a highest value of growers' share in the final price and a lower rank for a greater amount of marketing cost and marketing margin. The composite index was determined by combining individual indicators. Channel 6 was rated best in the growers' share of the final price, marketing margin, and marketing expense. The fewer intermediaries in channel 6 resulted in a decreased marketing profit in this channel. In channels 4 and 5, the growers' received a higher price due to the simplicity of purchasing in bulk from the large-scale farmers. Though channel 6 emerged as the most effective, most marginal and small farmers did not utilize it due to lack of infrastructural facilities (cold stores) in the study region. The next most profitable channels were 5 and 4. Again, large-scale farmers were more likely to participate in these channels.

Table 4 Marketing efficiency of different channels based on composite index method

Channel	Net share of grower %	(Rank)	Marketing costs %	(Rank)	Marketing margins %	(Rank)	*Ri* Score	Mean Score	Rank
Channel 1	37.98	(6)	37.80	(6)	23.36	(6)	18	3	6
Channel 2	40.17	(5)	37.38	(5)	21.28	(5)	15	2.5	5
Channel 3	43.72	(4)	36.33	(4)	19.23	(4)	12	2	4
Channel 4	50.45	(3)	31.96	(3)	17.16	(2)	7	1.16	3
Channel 5	50.90	(2)	30.19	(1)	17.40	(3)	6	1	2
Channel 6	55.5	(1)	33.84	(3)	12.10	(1)	5	0.83	1

Source Compiled by authors

Table 5 Result of ANOVA on comparison of efficiency of different apple marketing channels

Efficiency	Sum of Squares	df	Mean square	F	Sig.
Between groups	0.972	5	1.409	30.94	.000
Within groups	0.157	25	.356		
Total	1.129	30			

Source Computed by authors

Results of Analysis of Variance

The one-way ANOVA was used to determine the significance of efficiency difference between the channels. Table 5 displays the outcome of the ANOVA:

The F statistic of ANOVA was found significant at 1 per cent level. Thus, the hypothesis that 'the mean marketing efficiencies of the channels are significantly different' is accepted.

Conclusions

The study has identified the prevalent apple marketing channels in the Kashmir valley, and measured their marketing efficiencies. It has compared the shares received by the growers in consumer rupee. Based on a primary survey, the study has identified six apple marketing channels in the Kashmir valley. Among them, channel 4 (local fruit market centres) has revealed the highest share of fruit (apple) marketed due to the ease of selling produce in the nearby markets and realise better rates through direct sale. In addition, the study has evaluated the cost-effectiveness of apple marketing channels widespread in Kashmir Valley. The study has indicated that apple marketed through cold storages (channel 6) was the most cost-effective. The distribution route has been characterized by low price spreads, a larger share of growers, and lower marketing margins for the intermediaries. The farmers who sell their apples directly to the wholesale markets (local or outside state markets: - channels 4 and 5), received better prices than those who sell at the farm gate (channels 1, 2, and 3). As per the analysis, the apple growers can get 17.52 percent higher share in the final prices using more efficient route to sell their produce. The shorter channels are more beneficial to the growers and more efficient than the longer ones. Conversely, most apple growers in the study region continue to deliver their produce to the local collectors and assemblers at the farm gate.

The Study has recommended that apple growers should be encouraged to sell their produce directly to the fruit market centres/ wholesalers, and for this access to credit should be provided. Channels 6, 5 and 4 being the more efficient apple marketing channels, inadequate infrastructure is compelling the growers to opt for alternative routes. Presently, the study area has ten functional fruit market centres, but only one of them (Sopore fruit market in the district Baramulla) has adequate facilities and has performed well in terms of marketing. The cold storage channel (channel 6) has been identified as the most efficient marketing channel; however, the region lacks this facility, with only 30 cold storage units capable of storing up to 10-12 percent of the total produce. It is important to bring improvements in marketing infrastructure in the existing fruit market centres and expansion of cold storage facilities across the valley.

The study has revealed that intermediaries play a crucial role in determining the growers' share in the final prices, and they often take a large portion of the final price, leaving a small share for growers. We recommend that apple growers should be provided proper marketing management training and price information through workshops and training sessions to increase marketing effectiveness, lowering marketing expenditures and increasing farmers' income.

Acknowledgments

I would like to express my sincere gratitude to all individuals who have provided assistance and support during the course of this research.

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Received 19 September 2023 Accepted 10 January 2024

Agricultural Economics Research Review 2024, 37 (1), 133-142
DOI: 10.5958/0974-0279.2024.00008.X

Can livestock sector reduce inequality in rural India? An economic analysis of trends and drivers of growth in livestock sector

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Abstract This paper analyses the development of the livestock sector since independence of India. Using livestock census data, it examines the trends particularly size, structure and compositional changes in the number of livestock held by households. It analyses the various socioeconomic determinants of the number of livestock held by the households in India using the Poisson regression. It highlights the inequality and variations in livestock holdings across households belonging to different socio-economic groups and finally suggests certain policy measures that could overcome the constraints faced by this sector and could help in raising farmers income by reducing inequality in livestock holdings in India.

Key words Livestock holdings, landholdings, Parameters, Poisson regression

JEL codes Q22, Q100, Q150

Introduction

The livestock sector plays a significant role in the socio-economic development of rural households in India. Its contribution to national Gross Domestic Product is around 5.1 per cent and towards agricultural gross domestic product it is around 29 per cent. As per the 20th Livestock Census 2019, the total livestock population had an increase of 4.6 per cent over the Livestock Census 2012. The share of livestock has been increasing faster in agricultural sector GDP growth than in the agricultural and allied sector growth (National Accounts Statistics GoI 2019) in the past one decade because of the rising demand for livestock products propelled by rising income, population and the urbanization. The national agriculture policy has identified livestock as an important sector and therefore livestock sector is likely to emerge as an engine of agricultural growth in the coming decades.

The livestock sector provides a variety of food and non-food products - milk, meat, wool and eggs. India is the largest producer of milk in the world with an annual production of 198.4 million tonnes in 2019-2020; it was about 23 per cent of world milk production (GoI, 2020). The gross value added from milk products within the livestock sector across India amounted to over 4.4 trillion Indian rupees in the fiscal year 2018 (Statista Research Department, 2021). This group of products made up 66 percent of the economic value in this sector. The contribution of livestock products to the Indian economy is of over 6.8 trillion rupees in 2018. Since the beginning of operation flood in India in early 1970s, milk production as well as its per capita availability have been increasing continuously (Statista Research Department, 2021). But, if we compare the per capita availability of milk in India with other countries in the world, India remains far behind. Several reasons are responsible for this. A major reason is that India despite having one of the largest number of animals, has low per capita milk availability, which signifies unproductive animals. It may be due to problems of feed and fodder, veterinary services, infrastructure, procurement of milk, etc. (Landes et al., 2017, Birthal and Jha, 2005). Moreover, the large population of India is also an important factor for low per capita milk availability.

India has a large animal diversity. India holds more than a quarter of world's bovine population, and with a production of more than 133 million tons in 2012-2013, it become the largest producer of milk in the world (Kishore et al., 2016). Among bovine animals, the buffaloes which constitute around 36 per cent of total bovine animals have 49 per cent share in milk production. The indigenous cows, on the other hand which constitute around 47.4 per cent of total bovine animals have only 21 per cent share in milk production. The cross-breed cows which comprise 16 per cent, have 27 per cent share in milk production. This is mainly due to the differences in milk yield across these three varieties of bovine animals (GoI, 2019).

Despite a significant role of livestock in India's agricultural sector, particularly in contributing towards the economy and livelihood of millions of people, there is a lack of studies that analyse the trends and patterns of livestock development in the country, both comprehensively and systematically. By identifying the factors influencing these trends, we can gain insights into the challenges and opportunities facing the livestock sector. This information would help in formulating policies and interventions to promote sustainable development of the livestock sector in India. More specifically, this paper identifies the drivers of these patterns using Livestock Census (1960-2019), supplemented by an analysis of the household-level data from a large-scale survey on Land and Livestock Holdings conducted by the National Sample Survey Organization (GoI, 1997; GoI, 2006; GoI, 2016). This paper analyses the overall trends in the livestock sector and thereafter focusses on the holdings of bovine animals which constitute a mamoth share in total bovine holdings.

This paper also analyses the inequality in livestock holdings in India. The inequality in livestock holdings has various social, economic and environmental implications. For example, it can lead to economic disparities among livestock farmers. The recent literature has revealed that distribution of livestock is closely related to landholdings (Birwal, 2017; Vaidyanathan, 1988). The farmers have a greater access to resources, markets, and technologies, giving them a competitive advantage over small farmers. This can perpetuate poverty and hinder the overall economic development of the livestock sector. The inequality in landholdings could also accentuate social stratification and marginalization of small and marginalized farmers. It could also lead to negative environmental consequences such as overgrazing, deforestation and pollution with an impact on biodiversity and ecosystem services. Understanding and addressing this inequality is crucial in promoting inclusive and sustainable livestock development. It would help reduce poverty, enhance food security, and promote environmental sustainability in the livestock sector. Hence, using the Poisson regression technique, we analysed the impact of different socioeconomic factors determining the holdings of bovine animals in India using household level data collected by the Land and Livestock Survey, NSSO (figure based on year 2019).

Trends in livestock population growth in India

Table 1 gives details of livestock population in India using data from the Livestock Census from 1961 to 2019. India has a huge livestock population of 185 million 'cows & bullocks', 105 million buffaloes, 215 million ovine animals (goats & sheep) and 8 million pigs (figures based on year 2019). Out of the total livestock in the country, around 36.04 per cent are 'cows & bullocks', 20.39 per cent are buffaloes, 41.76 per cent are ovine animals (sheep & goats) and only 1.59 per cent are pigs. All other animals are less than 0.25 per cent of the total livestock population. The composition of livestock population has changed over the past few decades. As can be seen from Table 1, the livestock population has increased continuously since 1961, except in mid 1970s, late 1990s and during 2007-2012. After a fall in the previous years (2007-2012), the overall livestock population has again shown a rising trend in recent years i.e. 2012-2019. This trend can be observed for two of the major compositions of livestock— bovine and ovine animals. However, the increase in bovine animals has just attained the 2007 levels.

A look at the bovine animals alone, in rural India reveals that, after reaching the highest growth (18.22 per cent) in 1977-1982, the growth rate started declining and became negative between 1992 (-0.38 per cent) and 2003 (-2.61 per cent). The growth in bovine animals' population recovered during 2003-2007, but declined again during 2007-2012, turning negative (-0.82 per cent); it recovered again during 2012-2019 (0.79 per cent) (computed from Table 1). In absolute terms, the bovine animals' population has increased from 267.6 million in 2003 to 290 million in 2019, unlike the two earlier periods when it showed a decline. With this increase in 2007, the bovine animals' population reached at an all time high level (Table 1).

The overall trend of declining stock of bovine animals during the decade of 1990s can be explained as a consequence of agrarian crisis. The agrarian crisis had not only caused rising landlessness, a decline in the average landholding of the marginal and small farmers, but also stagnation in foodgrain production. Since the by-products of foodgrain crops are the important source of fodder for most of these rural households, their access to fodder is likely become more constrained. Thus, a decline in access to fodder might have forced these rural households to dispense off their bovine animals in general and male bovine animals holdings in particular (Patnaik 2007; Mishra and Sharma, 1990; Kishore et al., 2016).

Table 1, indicates that the number of adult male bovine animals went down from 80 million in 1992 to 62.15 million in 2003. This number further declined to 36.94 million in 2019. This shows that the preference for holding a male bovine animal in the rural India has gone down over the period. The other crucial factor for such a severe decline could be the rise in opportunity cost of rearing a male bovine animal vis-à-vis renting facilities (which are easily accessible now a days) of machine implements for marginal and small farmers. The female bovine animals not only provide milk but are also used for reproduction. The number of female bovine animals increased continuously during 1961-2019. However, the rate of growth of adult female bovine animals and female bovine animals during 1992-2003 was less than that during the decade of 1982-1992. The growth rate seemed to have risen up again during 2003-2012 and in recent years the corresponding figures have increased by 14 per cent and 2.36 per cent for female bovine and adult female bovine animals, respectively. However, a look at the composition of female bovines, reveals that the growth rate of young female bovines is larger as compared to adult female bovines in the recent decade (2007-2019). Thus, the increase in female bovines is mainly attributed to the increase in young female bovines as compared to adult female bovine animals.

The decline in the growth of adult female productive population and a near constant growth in young calves occurred in the recent period (2007-2019) when milk prices were rising at an accelerated pace, at least in nominal terms. Only two situations could explain the decline in growth of adult female population; first, the attrition rate was high. Secondly, there was a slowdown in share of young stock coming into adulthood, though the absolute numbers may have been greater than before (Rajeshwaran et al., 2014).

The increase in population of female bovine animals during the 1970s and 1980s was related to the expansion of dairy cooperative movement and expansion of rural banking. During 1980s, the provision of subsidized credit for purchasing milch bovine animals was an important component of the integrated rural development programme (IRDP). In the 1990s, the steep decline in availability of formal sector credit in rural areas and a slowdown in expansion of dairy cooperative movement led to a decline in the growth of rural female bovine animal holdings (Swaminathan and Ramachandra, 2005).

In dairy farming sector, both buffaloes and cross-breed cows yield higher returns as compared to the indigenous cows. Also, it is generally seen that farmers' first preference is buffalo due to its adaptability to local conditions and higher fat content in milk in comparison to that of the cow. Further, the buffalo has inherent disease resistance vis-a-vis the cow (Prasad, 2002). Even then the percentage of female stock accounted for substantially higher proportion of indigenous cows, followed by buffaloes and cross-breed cows. The cow (crossbreed and indigenous) seemed to have lost its importance since 1997, falling from 59.2 per cent of female bovine animals (cow plus buffaloes) in 1997 to 57.3 per cent in 2007 and in 2012, as compared to the proportion of buffaloes, it being 40.8 per cent of female bovine animals (cow plus buffaloes) in 1997 with further rise to 42.7 per cent in 2007 and remaining about the same in 2012. The decline in cow stock had been a result of proportionate decline in the indigenous cows, whereas the percentage of crossbred cows had increased. But, in recent years (2012-19), cow has again gained its importance increasing back to 59.13 per cent of female bovine animals, whereas the proportion of

Table 1 Population of livestock in rural India based on Livestock Census: 1961-2019 (in millions)

Livestock	1961	1967	1972	1977	1982	1987	1992	1997	2003	2007	2012	2019
Adult bullock	70.9	71.6	72	65.8	70.8	72.4	72.2	66.5	55.7	54.8	48.1	33.4
Young bullock	22	22.5	21.8	20.1	24.5	25.1	26.1	25.7	23.6	26.5	18.3	13.7
Total Bullock	92.9	94.1	93.8	85.9	95.3	97.4	98.3	92.2	79.3	81.3	66.5	46.5
Adult cow	52.3	52.6	53.3	50.8	56.1	58.7	61	60.7	60.4	68.8	73.1	77.2
Young cow	23.1	23.8	23.1	22	30.2	34.7	36.6	36.8	35.9	40.2	44.2	61.5
Total cow	75.4	76.4	76.5	72.9	86.3	93.4	97.6	97.5	96.3	109	117.3	138.8
Crossbred cow & bullock	NA	NA	NA	NA	7.9	9.8	13.5	17.9	21.9	30	36.8	47.8
Indigenous cow & bullock	NA	NA	NA	NA	174.6	180.9	182.4	171.8	153.7	160.3	146.9	137.5
Cow and bullock	170.4	170.5	172.4	158.7	185.8	190.7	195.9	189.7	175.7	190.3	183.7	185.3
Adult male buffaloes	7.51	7.99	7.79	7.36	7.74	7.12	7.88	7.58	6.42	6.21	5.15	3.5
Young male buffaloes	6.27	6.13	6.67	6.71	7.05	8.01	8.9	10.2	10.6	12.6	10.4	5.4
Total male buffaloes	13.8	14.1	14.5	14.1	14.8	15.1	16.8	17.8	17	18.8	15.5	8.9
Adult female buffaloes	23.8	24.8	27.4	28	30.7	36.7	41.3	44	47.6	51.4	53.9	52.3
Young female buffaloes	11.4	11.7	12.4	12.6	16.5	19.8	21.9	23.3	27.4	29.8	34.7	43.6
Total female buffaloes	35.2	36.5	39.8	40.6	47.1	56.5	63.1	67.3	74.9	81.1	88.6	95.9
All buffaloes (Male & female)	49.2	50.6	54.7	54.7	66.5	71.6	79.9	85.1	91.9	99.9	104.1	104.8
Adult male bovine animals	78.4	79.6	79.8	73.2	78.6	79.5	80.1	74.1	62.2	61	53.3	36.9
Young male bovine animals	28.2	28.6	28.4	26.8	31.5	33.1	35	35.9	34.2	39.1	28.7	18.5
Total male bovine animals	106.6	108.2	108.3	99.9	110.1	112.6	115	110	96.3	100.1	82	55.4
Adult female bovine animals	76.1	77.4	80.7	78.9	86.8	95.3	102.3	104.7	108	120.2	126.9	129.5
Young female bovine animals	34.5	35.5	35.5	34.6	46.6	54.6	58.5	60.1	63.3	70	78.9	105.1
Total female bovine animals	110.6	112.8	116.2	113.5	133.4	149.9	160.8	164.8	171.3	190.2	205.9	234.6
All bovine animals	219.6	221.1	227.1	213.4	252.3	262.3	275.8	274.8	267.6	290.2	287.8	290.1
Sheep	39.4	41.1	39.1	38.8	47.5	42	48.9	55.4	58	69.6	63.8	72.2
Goats	58.8	62.4	64.8	62.7	91.7	104.2	109.4	116.7	117.5	133.3	129.1	142.4
Ovine animals	98.1	103.5	103.9	101.6	139.2	146.2	158.2	172.2	175.5	202.9	192.8	214.7
Pigs	4.9	4.6	6.4	5.9	9	9.7	11.3	11.5	11.4	10	9.2	8.2
Total livestock	325.7	332.2	340.3	323.7	403.5	421.6	448.2	461.2	456.8	505	492.4	514.1

Source Authors' estimation from Livestock Census various reports (1961-2019) buffaloes has again fall to 40.87 percent. Further, there is a shift away from indigenous cow to buffalo and crossbreed cow holding.

Relationship between land and bovine holdings

The analysis of relationship between land and bovine holdings has revealed two features. First, in general, the distribution of bovine holding is less unequal than the distribution of landholding. Second, the distribution of bovine animals is closely related to landholdings. Land holdings facilitate, through provisioning of fodder, holding of male and female bovine animals.

The NSS survey data reveals the percentage distribution of livestock across various land sizes in 1991-1992, 2002-2003 and 2012-2013 (Table 2). The data shows that landless households own very little livestock in general. In 2002-03, about 32.0 per cent of the total rural households were landless and were holding a very little share of the total livestock. They had a relatively higher proportion of ovine animals (2.12%) and pig (3.17%) holding as compared to bovine animals holding (0.60%). the proportion of landless households increased very sharply between 1991-1992 and 2002-2003 which further increased between 2002-2003 and 2012-2013. Characterized by higher landlessness, the number of bovine animals owned by landless households fell by 74 per cent during 1991-1992 and 2002-2003, but between 2002-2003 and 2012-2013, the number of bovine animals holding increased more than 7-times.

The share of bovine animals owned by the households having marginal and small landholdings has been found higher than the share of land owned by these households. Together these categories owned 74 per cent of the bovine animals stock of the country (2012-2013). The marginal land owners (0.002-1ha) owned 51.26 per cent of total bovine animals stock and 22.17 per cent of operated area in 2002-2003, this increased to 54.59 per cent of total bovine animals stock and 28.82 per cent of operated area in 2012-2013. This contradiction can be explained in terms of difference in bovine holdings per hundred households and the the percentage distribution of bovine holdings across different landholding categories. If we examine the bovine holdings per hundred households, we find that 'large' farmers own large livestock compared to those with smaller landholdings. This could be because of the positive relationship between landholdings and livestock holdings, as land is essential for providing feed and fodder to sustain large livestock. On the other hand, when we look at the percentage distribution of bovine holdings across different landholding categories, we find that a small and marginal farmers possess a greater share of bovines compared to large farmers. This suggests that despite the existing inequalities in livestock holdings, the 'marginal' and 'small' landholdings farmers, with limited access to livelihood opportunities, utilize their land to support a higher number of bovines than large farmer do. Given that agricultural land is the most important source of fodder for most rural households, these data suggest that the fodder producing capacity of land operated by large farmers is utilized sub-optimally for the maintenance of bovine animals holdings.

It can be seen from Table 2 that there is a positive association between per hundred household bovine holding (male as well as female bovines) and their operated land size categories.

Table also reveals a steep rise in the number of landless households between 1991-1992 and 2002-2003 and a still higher decline in the number of male and female bovine animals held by them during this period. Though landlessness increased further in 2012-2013, the number of male and female bovine animals held by them increased substantially between 2002-03 and 2012-13.

In the case of marginal and small farmers, on the other hand, the number of bovine animal holdings increased more than the increase in proportion of these households between 1991-1992 and 2002-2003 (table 2). In 2012-2013, the proportion of households in marginal category increased while that in small category decreased, but their bovine animals holdings (both marginal and small) per hundred households decreased. The data suggests that households in these categories, given the limited access to fodder and other resources, shifted from their ownership of male bovine animals to female bovine animals. This might have been accompanied by a shift to renting of tractors and other machinery for meeting their draught power requirements. It is important to mention here that in addition to breeding, the male animals are kept for multiple purposes such as transportation, land traction,

Table 2 Size and distribution of land and livestock holdings: 1991-92, 2002-03 and 2012-13

Size class of household operational holding (ha)	Percentage									Animal holdings per 100 households					
	Households in landholdings			Operational landholdings size category			Bovine animals holdings			Male bovine			Female bovine		
	NSS rounds			NSS rounds			NSS rounds			NSS rounds			NSS rounds		
	48	59	70	48	59	70	48	59	70	48	59	70	48	59	70
Nil (d” 0.002)	21.8	31.9	32.2	0	0	0.0	2.5	0.6	5.4	5.9	0.8	7.2	15.2	2.1	15.9
Marginal (0.002-0.5)	33.6	33.4	35.3	5.5	8.6	11.5	23.2	29.9	32.3	57	44	34	83	96	92
Marginal (0.5-1)	14.7	13.8	14.5	10.1	13.6	17.3	19.3	21.4	22.3	138	101	79	129	141	134
Small (1-2)	14.2	11.2	10.4	18.7	20.6	23.2	22.6	21.1	19.4	162	124	94	160	169	164
Semi-medium (2-4)	9.7	6.23	5.34	24.1	22.4	22.5	17.2	14.9	12.7	168	151	110	192	222	218
Medium (4-10)	4.9	2.9	2.1	26.4	22.6	19.5	9.8	9.3	6.7	168	178	155	238	317	286
Large (>10)	1.1	0.6	0.3	15.2	12.2	6.1	2.5	2.6	1.4	148	215	218	329	532	528
All sizes	100	100	100	100	100	100	100	100	100	90	59	45	107	97	93

Source Authors' estimation from NSSO unit-level data of Land and Livestock Surveys various rounds

irrigation, etc. Although mechanization has revealed a similar impact on all size-categories of land holdings, the large farmers still maintain some males for breeding and other purposes. On the other hand, the landless households shifted to female bovines to avoid the high cost of maintaining male animals and also because of availability of rented tractors and machinery for agricultural operations.

In the higher land holding size-category although the proportion of their households had declined, there was an increase in the absolute number of female bovine animals held by them between 1991-1992 and 2002-2003. From 2002-03 to 2012-13, there was a decline in the per hundred households' male and female bovine animal holdings of semi-medium to large category holding households (Table 2).

These trends from Table 2 suggest that after 1990s it became increasingly more difficult for the landless households to maintain any type of livestock. On the other hand, the households with access to land, and consequently to fodder, chose to maintain a higher number of female bovine animals than earlier by reducing the number of male bovine animals held by them. The medium and large landholdings households increased their stock of both male and female bovine animals. The recent time period has on the contrary, has witnessed declining numbers of both male and female bovine animals for all sizes of landholdings households (except landless) and increase in their numbers for landless households. This suggests that apart from land, there could be other factors such as education level, employment, social groups, etc. that have impact on the bovine holdings of all land-size categories, except the landless. This motivated us to analyse the impact of various socio-economic factors on the number of bovine animal holdings by these households.

Determinants of number of bovine animals held by the households: A statistical Analysis

In this section, the determinants of number of bovine animal holdings by the household has been examined. Since, the number of bovine animals included the count values data, we have examined its determinants using the poisson regression. In this study, the dependent variable being the number of bovine holdings of a household, the Poisson regression would be most suitable to estimate. The model has been estimated using a maximum likelihood estimator.

Here, a number of household specific socioeconomic variables were considered in the regression analysis, such as land operated by a household, social group of the household, number of children in a household and education level of the members of the household. The education variable has been considered as highest and lowest education level of adult female and male members in the household.

Table 3 below presents the results of poisson regression of 35,604 households using 70th round of NSS data. The model has a pseudo R^2 of 0.2113. A study on the impact of caste groups on total number of bovine animals, revealed that as compared to 'Others' category, the households belonging to ST, OBCs, SC and muslims category held significantly less bovine animals. The coefficient of SC, ST , OBCs and muslim dummy has been found to be negative and significant at 1 percent level. Similarly, all the land size categories' (landless, semi-marginal, marginal, small, semi-medium and medium) dummy had a negative and significant impact on the number of bovine animals, implying that these land size category households own less number of bovine animals as compared to large category households.

The results of this study have shown that households belonging to large category of land holdings held more bovines as compared to the remaining categories. Similarly, households belonging to 'Others' social groups held more bovines as compared to the remaining categories. Now in order to understand, how far the operated land across various social groups is impacting the determinants of number of bovine animals, we introduced the interaction of operated land across various social groups.

The coefficient of interaction of ST with operated land has been found highest and positively significant, implying that as land owned by farmers in the ST category increases, the number of animals held by them also increases. This is justifiable as ST households mainly reside in tribal/hilly areas where landholdings are a major constraint. Thus, if ST category households are given more land then it could motivate them to hold more bovines since the problem of feed and fodder would not arise.

Similarly, for 'Others' and OBC categories of households, the land plays an important role as a determinant of number of landholdings, whereas the coefficient of interaction of SC and muslim categories of households with operated land is insignificant. It implies that land does not play an important role in the holding of bovine animals for SC and muslim categories of households, rather there could be certain other factors such as social taboos, etc. that could impact their holdings of bovine animals.

The coefficient of the number of children in a household and the number of members whose education level is below class Xth has been found positive and significant, implying that as number of children in a household increases, the demand for milk also increases, which in turn, motivates the household to increase their holdings of bovine animals. Also, households with low level of education have lesser

Table 3 Determinants of number of bovine holdings by the households: Poisson regression analysis

Dependent Variable	Total number of bovine		
	Coefficient	Standard error	P>|z|
Independent Variables			
Social group ref. category= Others			
SC dummy	-0.258	0.020	0.000
ST dummy	-0.218	0.017	0.000
Muslim dummy	-0.251	0.021	0.000
OBC dummy	-0.031	0.012	0.011
Land size categories ref. category= Landless			
Landless dummy	-2.682	0.059	0.000
Semi-marginal dummy	-1.046	0.056	0.000
Marginal dummy	-0.688	0.548	0.000
Small dummy	-0.555	0.053	0.000
Semi-medium dummy	-0.324	0.050	0.000
Medium dummy	-0.167	0.045	0.000
Interaction term			
SC*Operated land	0.006	0.009	0.520
ST*Operated land	0.054	0.007	0.000
Muslim*Operated land	0.001	0.007	0.880
OBC*Operated land	0.013	0.003	0.000
Others*Operated land	0.019	0.003	0.000
Education level			
Number of members below 10th	0.093	0.002	0.000
Lowest female education in household	-0.033	0.001	0.000
No. of children in household (<14)	0.030	0.002	0.000
Constant	1.295		
No. of Observations	35604		
Pseudo R2	0.2113		

Source Computed using Stata Software

avenues to earn their livelihoods and thus choose livestock as a source of their income. It is seen that the female members of the households are particularly involved in animal-rearing. Our results have shown that lower the level of female education in a household, the more are their holdings of bovine animals.

The study has shown that land and social groups are significant determinants of the number of bovine animals held by the households. In the absence of the alternative sources of employment, bovine holding and dairying could be a significant source of income, nutrition and risk diversification for these households. But, because of credit constraints and dependence on larger landholding households for fodder, it was found that relatively smaller herd size was kept by the landless households, and small and marginal farmers instead of keeping large number of bovines. On the other hand, the medium and large farmers, despite having enough fodder availability, face constraints in terms of labour availability, since animal husbandry is a labour intensive work, and adult members of the household may be unwilling to rear animals, hired labour could be costly and these households are unwilling to bear the cost of hiring outside labour throughout the year.

Conclusion

The paper analyses the trends in livestock holdings in India using data of Livestock Census from 1961 to 2019. As per the data, the livestock holdings increased continuously till late 1990s, except during 1972-77. During the mid1970s, late 1990s and again in recent years (2007-12), there had been a decline in livestock holdings. Data also shows an increase in the proportion of female bovine animals in the total bovine animals over the period of study.

The period between 1991-92 and 2002-03 was characterized by a marked fall in agricultural growth, steeply rising landlessness and inequality in landholdings. This continued even during 2002-03 and again in 2012-13 when landlessness and inequality in landholdings increased. In this backdrop, the paper has analysed the relationship between animal holdings and size of operational landholdings.

The analysis of large-scale survey data of(NSS 48th ,59th and 70th rounds) shows that the ownership of livestock was extremely unequal across households in different size-classes of operational holdings. In general, the landless and small peasants owned fewer livestock heads than households in higher size-classes of landholdings. It was also noted that the trends over time in livestock holdings had also not been uniform across all land sizes. The steepest decline in livestock holdings happened for landless and small farmers in 2002-03. In contrast, the livestock holdings of households in the highest size-class of operational holdings went up during the 1990s. In the case of small and marginal farmers, an overall decline in bovine animals holdings was accompanied by a compositional shift away from holding of draught animals towards holding of milch animals. In contrast, in the case of medium and large farmers, the compositional shift towards female bovine animals was a result of higher increase in milch bovine animals than in draught animals. On the other hand, during 2002-03 and 2012-13 there was a further decline in per hundred bovine animals holdings for all land-size categories, except for landless households, for whom there was an increase in bovine animals holdings.

Using the Poisson regression analysis on the 70th round of NSS data , the paper has analyzed the impact of various socio-economic factors on the number of bovine animals held by a household. It was found that households belonging to large category of landholdings as well as ‘Others’ social groups had more bovines as compared to their counterparts. In order to understand, how far operated land across various social groups is impacting the determinants of the number of bovine animals, we introduced the interaction of operated land across various social groups. The results have depicted that land does not play an important role in the holding of bovine animals for SC and muslim household categories, rather there could be certain other factors such as social taboos, etc. that could impact their holdings of bovine animals.

The paper has highlighted inequality in livestock holdings among various farm households in terms of either larger holdings of livestock with the large farmers vis-à-vis small farmers and the landless or the holding of expensive animals like bovine animals by large farmers vis-à-vis small ruminants by the economically weak households. This inequality further increased between 1991-92 and 2002-03 when there was a big rise in the extent of landlessness. In the case of marginal and small farmers, there was an overall decline in bovine animals holdings. This decline was a result of a steep fall in holdings of male bovine animals and a small increase in holding of female bovine animals. As a result, there was a change in the composition of livestock towards milch animal stock. In the case of large farmers, there was an increase in overall bovine animal holdings; the increase in holdings of milch bovine animals was higher than the increase in holdings of male bovine animals. This continued even during 2002-03 and 2012-13 where again landlessness and inequality in landholdings increased and again per hundred households male and female bovine animals declined for all landholdings categories, except landless households.

It is arguable that the state policies which were designed to give a boost to the livestock sector have not been able to provide needed support for the expansion of livestock holdings in the country. Most of these policies have been product-specific and have not focused on the entire range of products covered under the livestock sector. Secondly, their spread has been limited to a few developed states. Thirdly, the constraints faced by the farmers, specially the small and marginal farmers, have only been partially addressed by these policies, as some important issues like fodder availability remained out of the purview of these policies. Fourthly, under the Structural Adjustment Programme, during the decadal periods from 1991-92 to 2002-03 and 2002-03 to 2012-13, public programmes such as Integrated Rural Development Programme (IRDP) , for supporting the livestock sector were weakened considerably.

Given the immense potential of livestock sector in raising farmers income, reducing inequality and poverty in India, the government should promote policies that would benefit economically-poor and socially-deprived groups. These policies could be framed in a manner that the benefits could be distributed equally among various socio-economic groups in rural India.

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Received 29 December 2023 Accepted 28 March 2024

Agricultural Economics Research Review 2024, 37 (1), 143-145

Abstract of PhD thesis

Policies for food security in India: Comparative study of 'In-Kind' food transfer and 'In-Cash' direct transfer in Puducherry

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The Public Distribution System (PDS) in India is one of the most important economic and social welfare programmes, which is aimed to address the hunger and poverty among the poor. The food is supplied through the fair price shops to the the rural and urban households as per their categorization - Below Poverty Line (BPL), Above Poverty Line (APL), and the poorest of the poor under the Antyodaya Anna Yojana (AAY). However, the PDS has been criticized on account of the poor targeting, leakages, delivery challenges such as untimely delivery and corruption, and increasing public expenditure on account of the subsidized food availability. To counter these challenges under the existing 'in kind' food transfers, rationale is given for a 'Direct Cash Transfers'(DCTs), as an alternative policy. However, the debate on the type of transfers (food -in kind vs cash) to the poor has received attention in the last decade. As per the Neo-classical economics theory, the demand and supply dynamics in the production, pricing and consumption of goods and services should be taken into consideration. Going by the cash transfers, cash and food transfers should hypothetically have an equal effect on food consumption. It is also connected to the economics of indifference curves for consumer preferences (choices).

The government of India introduced DCT on experimental basis in one north region viz. Chandigarh and other in the south region viz. Puducherry. Keeping in view the larger debate on food security in India and the need to fulfill the hunger of the poor and destitute, the present research aims to understand whether the shift from 'in-kind' food transfers through the PDS, to the DCT will achieve the objectives. Going by the FAO (2013) definition of food security as the availability of food, accessibility and utilization, the core objective taken up is - 'whether', 'how' and 'to what extent' the DCT would meet the food security among the poor. The thesis was submitted in 2018 to the Tata Institute of Social Sciences, Mumbai under the supervision of Prof. Madhushree Sekher. Following are the broad objectives of the study.

1. To analyze the perceived advantages and disadvantages of 'In-Kind' Food Transfer and 'In-Cash' Direct Transfer (DCT) schemes for the Public.
2. To find association between the preferences of the households for 'In-Kind' Food Transfer and 'In-Cash' Direct Transfer, in their socio-economic contexts.
3. To study the views of 'fair price shops' employees, banks and civil supply officials regarding the actual and perceived changes in the institutional system of food supply vs cash transfers.

Methodology

The research approach adopted was exploratory and descriptive. It was conducted in the Union Territory of Puducherry, where 'In-Cash' Direct Cash Transfer (DCT) were introduced on trial basis. As on February 2015 (Government of Puducherry record), there were about 4.35 lakh BPL and AAY households who were covered under the DBT scheme. The sample households in the study area were selected based on the simple random sampling technique. In all 400 HHs were chosen. We covered 5% of the total number of households covered in Puducherry by the government under the DCT program. Veering 5% error margin and 95% level of significance, a sample size of 400 households was considered ideal for the doctoral research.

Data collection

Semi-Structured Interview Schedule and In-depth Interview Schedule including field observations were planned. Secondary data was collected from the civil supply department report (Sources: Civil supply report 2013 to 2017) and analyzed using Statistical tests (t-test), Chi^2 test, cross-table, simple regression techniques and suitable Econometrics Model of Multinomial Logistic Regression (M-Logit). A few detailed case-studies of households were also attempted, particularly covering the women headed households to get some insight on their preferences for two schemes. The Interview schedules were coded manually under different concepts, themes.

Key findings

Experiences of food vs cash transfers

We find many of the respondents were females who know the household status better than the males. Rice is the staple food among the households and they reported their dependence on fair price shops for it. The BPL and AAY respondents were benefited by two schemes. That is, exchange of goods and money. However, the respondents' dietary patterns have changed since the introduction of DBT, as choices for food items have increased. According to the respondents, the safety-net mechanism has been very successful. Most of them feel that In-kind transfer makes more sense for the overall welfare of the family.

Fair Price Shops and dealers are more supportive of poor families. There is no corruption and leakage in the study area. The satisfaction of food exchange is excellent due to proper operation and use. Since the safety net mechanism of DBT falls under a central subsidy scheme, the state government does not interfere. Respondents have different views about the implemented DBT program. They revealed that the cash amount was received within 15 days in their bank accounts. Direct Benefit transfer is not a door step delivery which creates complexity. Respondents' complaint that DBT is not satisfactory. Most of the female respondents feel that cash is not enough, especially where there are more members in a family. Hospitality to guests is prohibited and food insecurity issues arise in the direct benefit exchanges. It was reported that in-kind food exchanges are effective when rice, sugar, salt, soap, oil and kerosene and additional grains are provided at affordable prices. Additional food grains were received to poor families during the festival time.

Advancement in technology at FPS outlets, use of SMS to inform availability of goods, use of smart cards, computerized and biometric systems are the best features of inter-type exchanges. Respondents have been satisfied with the food transfer for the last three years. Although there were some complaints, the Grievance Division resolved it promptly.

Most of the respondents received cash, while some households did not receive it at all. It is also said that the authorities do not heed the complaints. Respondents complain that banks and ATMs are far from homes and bank officials are uncooperative. Hence, travel costs and time to visit banks are high. Therefore, there should be more transparency for ease of use so that even poor families can use them without difficulty. There are other benefits of the DBT scheme. Respondents said they opened the bank accounts and used ATM cards for the first time. There is scarcity of cash, so it cannot be used for various purposes. However, the first monetary transaction is in the urban areas, then in the semi-urban areas and finally in the rural areas. Customers of these areas delayed to receive cash every two to three weeks every month.

Preferences of the households

The respondent's choice is imperative for their food security. It is based on their socio-economic variables. The variables considered in this study were gender, education, marital status, religion, caste, household members, type of households, dwelling, occupation(s), household assets, ration cards, received benefits, transport cost, utilisation of cash, accessibility of ATMs, and the market price of food. A total of sixteen variables out of thirteen were taken to estimate the M-logit model. Most respondents under the BPL and AAY preferred in-kind food transfer while fewer preferred cash over food exchange or both schemes together. Regarding direct cash transfer, there were mixed opinions, cash amounts may be misused by males but females used cash for their household consumption and spending on their growing children.

In Puducherry the cash transfer issued only for the BPL and AAY cardholders. Each individual adult was credited Rs. 115 in the bank account. The consumers also benefited by the subsidized food grains. The bank account holders experienced problems while withdrawing the money from their bank account due to long distance, unawareness about the withdrawal forms etc. In addition, they were not informed about the deposit of money in their account. Circumstances were different in the rural areas in Puducherry. The study concluded on a mixed note about the in-kind vs cash transfers in the study area, the latter has less positive points compared to the former.

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