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Long Term Sustainability of Rice-Wheat Cropping System in Indo-Gangetic Plains of India: An Assessment with Total Factor Productivity Change

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Abstract
In India large proportion of population (54.6%) depends on agriculture for their livelihood contributing 17.4% of the country's Gross Value Added (GVA). The study presents a comprehensive evaluation of the long-term performance of the Rice-Wheat cropping system in the Indo-Gangetic plains of India over five decades (1970-71 to 2019-20). Assessing Total Factor productivity (TFP) across major states, the study reveals a troubling stagnation and decline in TFP for Rice, Wheat and the combined cropping system. Factors such as rising input costs, changing labour dynamics, ground water depletion and state-specific practices significantly impact productivity. Punjab benefits from progressive labour and mechanization, while Haryana faces declining productivity due to groundwater depletion. Uttar Pradesh realizes positive impacts from fertilizer use, while Bihar and west Bengal's reliance on traditional practices hampers productivity. Socio-economic factors like Net National Income and rural electrification affect TFP, highlighting complex influences on agricultural productivity. The study recommends institutional and structural changes, suggesting privatization through contract farming to enhance efficiency and knowledge among cultivators. Addressing these challenges is crucial for revitalizing agricultural productivity in the region, demanding a multifaceted approach encompassing technological innovation, sustainable practices and inclusive policy interventions.

Keywords: Rice-Wheat cropping system, total factor productivity, sustainable technology, institutional reform
JEL Codes: O390 Technological Change: Other
O330 Technological Change: Choices and Consequences; Diffusion Processes
O320 Management of Technological Innovation and R&D

Introduction:

India is predominantly an agriculture-based country where approximately 60 percent of the population is engaged in farming operation (Statista 2023). With the ever-growing population over last fifty years (2.2% in 1970-71 which has gone down to 1.0% in 2019-20) (World Bank 2022), the country has managed to produce 297.50 million tonnes of foodgrains in 2019-20; sufficient to cater the basic needs of the mass. In India, the two major foodgrains i.e.; Rice and Wheat have contributed 76.0% of the total foodgrains produced and cater >70% of the Indian population. The rest of the population consumes rice along with wheat or other grains (USDA, 2019).

Rice (*Oryza sativa* L.) - Wheat (*Triticum aestivum* L.) cropping system (RWCS) is the major backbone of Indian farming (Dhanda *et al.* 2022, Kumar *et al.*, Bhatt *et al.* 2021) over decades where > 85% is being distributed to Indo-Gangetic Plains (IGP) of India (Banjara *et al.* 2021). The rotation has spread covering about 9.2 million hectares of land (Kumar *et al.*, Jat *et al.* 2020) and mainly in the north-western parts of the country (Ambast *et al.* 2006, Nawaz *et al.* 2019). The RWCS is thus the key pillar of the nation's food security (Jat *et al.* 2020, Hobbs *et al.* 2003).

The advent of Green Revolution has the basic objectives to meet up the hunger crisis of the as well as to modernize agricultural practices in rural India aiming an overall institutional and structural reform of agricultural sector in India (Bhusan 2005, Kumar *et al.* 2000). IGP being the heart belt of green revolution, the share of rice and wheat production has been portrayed consistently an optimistic performance in providing employment and livelihood to millions (Sekar *et al.* 2012). Despite of a sustainable gain in production (2.13%) and rising productivity (2.19%) over last five decades due to technological innovation and dissemination at every corner of the country, the total factor-productivity of RWCS in IGP of India is stagnating and declining over past three decades (Chaudhary and Harrington 1993, Paroda *et al*. 1994, Sekar *et al.* 2012, Bhusan 2005, Bhatt *et al.* 2021). Excessive utilization of natural resources is another concern leading to environmental degradation as well as threatening sustainability of the system (Chauhan *et al.* 2012, Kumar *et al.* 2018, Sekar *et al.* 2012, Bhatt and Singh 2018, Srinivasrao *et al.* 2019). During the recent decade, the productivity of RWCS has stagnated or decreased mainly due to declining ground water table (Bhatt *et al.* 2020), deteriorated soil health, micro-nutrient deficiencies (Ladha *et al.* 2009), frequent and widespread insect pest infestation and climate change (Saini and Bhatt 2020, Pathak *et al.* 2003). Farmers of this region generally adopt conventional agricultural practices such as puddled transplanted rice followed by intensive tilled wheat which are water, capital and energy intensive (Bhatt *et al.*

2020, Singh *et al.* 2019). In addition, there has been wide disparity in yield which is continuously haunting IGP agriculture (Sekar *et al.* 2012). The future growth must come from yield rather than area, since the latter is declining day by day due to urbanization and industrialization (Hobbs *et al.* 2003).

Thus the time has come to recapitulate and re-address the performance of total factor productivity change for RWCS in IGP of India covering five major states (Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal) and also to identify the key factors and its various sources with reference to institutional and structural reforms, migration of agricultural labourer, unemployment scenario, advances in scientific research and extension work and contribution of public investment in R&D wing of the country over past five decades (1970-71 to 2019-20). Lastly some relevant policy measures have been recommended for the sake of achieving long term sustainability of RWCS in IGP India.

Materials and Methods:

Study area

The entire study is based on performance of RWCS over past fifty years in five major states under IGP of India, which comprises four distinct sub-regions: Trans-Gangetic regions (Punjab and Haryana), Upper Gangetic regions (Uttar Pradesh), Middle and Lower Gangetic regions (Bihar and West Bengal) (Singh et al. 2007).

Description of data

Secondary data on acreage production and productivity as well as cost of cultivation of rice and wheat across the IGP of India during 1970-71 to 2019-20 were gathered and compiled for computing TOI, TII and TFPI from the periodical issues of Cost of Cultivation of Principal Crops in India (1991, 1996, 2000) and official website of Directorate of Economics and Statistics (DES) Ministry of Agriculture, Govt. of India. Subsequently, the farm harvest prices from 1970-1997 have been gathered and compiled through periodical issues of "Farm Harvest Prices of Principal Crops in INDIA. Ministry of Agriculture, Govt. of India, India". However, rest of the required data regarding farm harvest prices from 1998-2019 have been collected from the same official website mentioned above. The various socio-economic indicators used as sources of TFP change have been collected from the periodical issues of Economic Survey, Govt. of India published since 1970-71 till 2020-21.

Computation of missing data

While, dealing with state-wise temporal data of cost of cultivation and various input use; the problems of un-availability of data in a few cases have been faced which had been catered by performing three-years or five-years moving average method.

Data limitation

The author has tried to accumulate almost all the socio-economic indicators that could drive the TFP of RWCS in the IGP of India; while failed to add the soil regime status and climatic factors that could have a direct influence on change in TFP over time. Climate change has a severe impact on total factor productivity that has not been incorporated in the study.

Empirical strategy

Total factor productivity (TFP)

It is used for quantifying and assessing the feasibility, viability and long-term sustainability of RWCS across the states temporally (Lynam and Herdt 1989; Ehui and Spencer 1993; Kumar et al. 2004). However, there were an innumerable study on TFP performed earlier using Divisia Tornqvist-Theil index model (Evenson and Jha 1973; Christensen 1975; Ball 1985), constituting a temporal modified trans-logarithmic production function. TFP indices have gained significant recognition through Divisia index after approximating Tornqvist-Theil discretion, disclosing consistent aggregation and linear homogenous trans-logarithmic production function (Diewert 1976; 1978).

Total output index (TOI): $TOI_{t-1} = \prod_j (Q_{jt} / Q_{jt-1})^{(S_{jt} + S_{jt-1})½}$

Total input index (TII): $TII_{t-1} = \prod_i (X_{it} / X_{it-1})^{(S'_{it} + S'_{it-1})½}$

Total factor productivity index (TFPI): $TFPI_t = (TOI_t / TII_t)$ = Total Output / Total Input

Here, TFPI represents ratio between Tornqvist aggregate output and input indices; t represents year; Q_{jt} displays j^{th} crop's output at year t, Q_{jt-1} represents j^{th} crop's output at time period (t – 1), S_{jt} displays j^{th} crop's proportional share of value to aggregate value of output at time period t; S_{jt-1} represents j^{th} crop's proportional share of value to aggregate value of output at time period (t-1); X_{it} displays i^{th} factor's amount at period t; X_{it-1} represents i^{th} factor's amount at time period (t – 1); S'_{it} shows i^{th} input's share to total input related cost at time period t; S'_{it-1} represents i^{th} input's share to total cost of inputs at (t – 1) period.

Chain Base Index has been used as the base to compute output, input and factor productivity index. Two consecutive time periods of t and (t-1) have been taken into consideration over the whole time period of t_0 to T, to estimate the above-mentioned indices by using chain-linking. After that, various indices are multiplied together:

TOI (t) = TOI (1). TOI (2) ……TOI (t-1)

TII (t) = TII (1). TII (2) ……TII (t-1)

$TFP_t = (TOI_t / TII_t)$

In order to measure these for the entire area, geometric mean of the respective indices of five selected states have been computed.

For computing the viability, price and inflation rate would be a major factor where agricultural price index for Rice and Wheat over last fifty years has to be considered while measuring TFP.

Data envelopment analysis (DEA)

Computation of Output oriented DEA-Malmquist TFP indices

However, Divisia Tornqvist-Theil Index model has considered output and various factors input in value terms where price effects are always there and can't be negated fully. Thus, Output oriented DEA-Malmquist index has been performed using DEAP version 2.1 (Coelli 1996; Coelli 1998) which includes output and inputs in quantity terms that would completely omit the price effects.

Malmquist productivity index

Output oriented s-technology: $m_0^s (q_s, q_t, x_s, x_t) = \frac{d_0^s (q_t, x_t)}{d_0^s (q_s, x_s)}$;

Output oriented t-technology: $m_0^t (q_s, q_t, x_s, x_t) = \frac{d_0^t (q_t, x_t)}{d_0^t (q_s, x_s)}$

Malmquist factor productivity index

It has been calculated by taking geometric mean of both measures at two different technology, s and t.

$$m_0 (q_s, q_t, x_s, x_t) = \left[m_0^s(q_s, q_t, x_s, x_t) \times m_0^t (q_s, q_t, x_s, x_t)\right]^{0.5}$$

$$= \left[\frac{d_0^s (q_t, x_t)}{d_0^s (q_s, x_s)} \times \frac{d_0^t (q_t, x_t)}{d_0^t (q_s, x_s)}\right]^{0.5}$$

Decomposition into two different components:

$$m_0(q_s,q_t,x_s,x_t) = \frac{d_0^t (q_t, x_t)}{d_0^s (q_s, x_s)} \left[\frac{d_0^s (q_t, x_t)}{d_0^t (q_t, x_t)} \times \frac{d_0^s (q_s, x_s)}{d_0^t (q_s, x_s)}\right]^{0.5}$$

Efficiency change	Technical change

Here, m_0^s and m_0^t represent measurements of s and t technologies, respectively. Meanwhile, q_s and q_t represent output level by using x_s and x_t input level at s and t technology, respectively.

Exponential growth rate

Growth rate of TOI, TII and TFPI over the year has been computed subsequently fitting modified exponential production function, like:

$Y = ae^{bt}$

Y represents output after period t, the intercept term is a and b is the growth factor.

% growth rate has been calculated as (antilog[b] – 1) ×100

Multiple Step-wise regressions

To find out the key factors contributing to change in TFP, multiple correlation and step-wise multiple regression method between TFP (Y) and various explanatory factors (X_1, X_2,……X_9) has been performed where,

$Y = f(X_1,\ldots\ldots\ldots\ldots X_9)$

Y=Total factor productivity, X_1=Seeds, X_2=Fertilizers, X_3=Manures, X_4=Irrigation, X_5=Machine labour, X_6=Pesticide, X_7=Bullocks used as labour, X_8=Humans used as labours, and X_9=Interest on working capital.

For identifying major socio-economic indicators affecting overall TFP of RWCS in the mentioned areas, a multiple log-linear production function between TFP indices with various explanatory socio-economic parameters is set temporally (1970-71 to 2019-20) with the following functional form: $Ln(TFP_t) = Ln(a) + \beta_{1t}Ln(GVA) + \beta_{2t}Ln(PC\_NNI) + \beta_{3t}Ln(GDCF) + \beta_{4t}Ln(WPI) + \beta_{5t}Ln(Coal) + \beta_{6t}Ln(Crude\_Oil) + \beta_{7t}Ln(Electricity) + \beta_{8t}Ln(Export) + \beta_{9t}Ln(Import) + \beta_{10t}Ln(Pop) + \beta_{11t}Ln(BR) + \beta_{12t}Ln(DR) + \beta_{13t}Ln(LEB) + \beta_{14t}Ln(Edu) + \beta_{15t}Ln(PE\_RD) + \beta_{16t}Ln(GDP\_Agri) + \beta_{17t}Ln(PE\_Agri) + \beta_{18t}Ln(PE\_Rural\_Dev) + \beta_{19t}Ln(PE\_Irri\_Flood) + \beta_{20t}Ln(PE\_Energy) + \beta_{21t}Ln(PE\_Industry) + \beta_{22t}Ln(PE\_Transport) + \beta_{23t}Ln(PE\_Comm) + \beta_{24t}Ln(PE\_Science\_Tech) + \beta_{25t}Ln(PE\_Eco) + \beta_{26t}Ln(PE\_Social) + \beta_{27t}Ln(PE\_General) + \beta_{28t}Ln(Cultivator\_Ag\_Worker) + \beta_{29t}Ln(GII) + \beta_{30t}Ln(Cr\_Issued) + \beta_{31t}Ln(Cr\_Outstanding)$

Here, TFP=Total factor productivity over time t, a=intercept term, GVA = gross value added at constant prices in rupees crores, PC_NNI = per capita net national income at factor cost at constant prices, GDCF = gross domestic capital formation as percentage of gross domestic product at current market prices, WPI = wholesale price index average, Coal=coal and lignite in million tonnes, Crude_Oil = itself in million tonnes, Electricity = its generated quantity in billion KWH, Export = export in rupees crores, Import = import in rupees crores, Pop = population in million, BR = rate of birth per 1000, DR = rate of death per 1000, LEB = life expectancy at birth in years, Edu = education as Literacy rate in percentage, PE_RD = Public Expenditure on Research and Development in rupees crores, GDP_Agri = gross domestic product from agriculture and allied Sector at 2006-07 prices, PE_Agri = public expenditure on agriculture and allied Activities in rupees crores, PE_Rural_Dev = public expenditure on rural development in rupees crores, PE_Irri_Flood = expenditure of Govt. on irrigation and flood control in rupees crores, PE_Energy = public expenditure on energy in rupees crores,

PE_Industry = public expenditure on industry and minerals in rupees crore, PE_Transport = public expenditure on transport in rupees crore, PE_Comm = public expenditure on communication in rupees crores, PE_Science_Tech = public expenditure on science, technology and environment in rupees crores, PE_Eco = public expenditure on general economic services in rupees crore, PE_Social = public expenditure on social services in rupees crores, PE_General = public expenditure on general services in rupees crores, Cultivator_Ag_Worker = population and agricultural workers in million, GII = gross irrigated area in million hectares, Cr_Issued = credit issued in crores, Cr_Outstanding = credit outstanding in crores.

Results and Discussion

Overall as well as decadal trends in TOI TII and TFPI for Rice, Wheat and RWCS have been computed for individual states as well as overall IGP of India for the last fifty years. It was observed that TFP of Rice, Wheat and RWCS in entire IGP of India is stagnating and declining over past five decades, where TFP Rice, Wheat and RWCS have registered a disappointing 0.12 per cent, -0.27 per cent and -0.18 per cent growth rates respectively. The growth rate of TFP Rice was significantly positive at second decade (2.57 per cent) while Wheat and RWCS have shown disappoint performance all through. For individual states under IGP, barring Uttar Pradesh, all the states are suffering from diminishing trend in TFP for Rice with a significantly negative growth rates in the Trans-Gangetic plain (Punjab and Haryana) as well as stagnant growth rates in the Lower Gangetic plain (Bihar and West Bengal) over past five decades. However, Uttar Pradesh has managed to gain TFP for Rice with a significant 1.28 per cent change over the period and so. While glancing at the decadal change in TFP for Rice, TOI has been declined for Punjab and Haryana as the decade progresses while TOI surpasses TII significantly in the first and fourth decade for Punjab (2.37 per cent and 1.14 per cent respectively) and only first decade for Haryana (4.57 per cent). TOI has gained its significant prominence over TII in the second decade for Uttar Pradesh, Bihar and West Bengal (5.76 per cent, 5.53 per cent and 7.49 per cent) resulting positive growths in TFP assuring technological change in paddy cultivation under IGP India during 1980-90. The study is in similar path with the previous findings of Flinn and De Datta (1984); Nambiar (1988); Kumar and Rosegrant (1994); Cassman and Pingali (1995); Greenlands (1997); Pingali *et al*. (1997); Dawe *et al*. (2000), Yadav *et al*. (2000); Kumar and Yadav (2001); Sekar *et al*. (2012); Chatterjee *et al*.

(2013); Chatterjee *et al*. (2015); and Chatterjee (2017) that TFP for Rice in the IGP of India has a sharp fall after 1980's.

Table 1: Exponential growth rates of Indices for Rice in IGP of India (1970-20):

States	Index	1970-80	1980-90	1990-00	2000-10	2010-20	1970-20
Punjab	TOI	4.91**	0.75 NS	-0.22 NS	1.77**	1.07*	**1.21****
	TII	2.48*	0.60 NS	2.22**	0.62 NS	2.32**	**2.20****
	TFPI	2.37 NS	0.15 NS	-2.38**	1.14 NS	-1.22 NS	**-0.97****
Haryana	TOI	4.81 NS	0.04 NS	-1.81 NS	1.69 NS	0.35 NS	**1.03****
	TII	0.22 NS	2.79**	0.26 NS	1.62 NS	-0.82 NS	**2.50****
	TFPI	4.57 NS	2.68**	-2.07 NS	0.07 NS	1.17 NS	**-1.44****
Uttar Pradesh	TOI	-0.10 NS	5.76**	2.60**	0.61 NS	1.34 NS	**2.47****
	TII	0.99**	0.34 NS	-0.07 NS	1.62 NS	-0.09 NS	**1.18****
	TFPI	-1.08 NS	5.40*	2.67**	-1.00 NS	1.43 NS	**1.28****
Bihar	TOI	-1.23 NS	5.53*	4.67 NS	-0.83 NS	0.79 NS	**1.92****
	TII	2.43*	1.88**	0.11 NS	0.98 NS	0.64 NS	**0.96****
	TFPI	-3.57 NS	3.58 NS	4.55 NS	-1.79 NS	0.14 NS	**0.94****
West Bengal	TOI	1.17 NS	7.49**	1.36*	0.33 NS	1.06**	**2.19****
	TII	2.88 NS	0.73*	1.67 NS	1.02*	-1.27*	**1.36****
	TFPI	-1.66 NS	6.71**	-0.30 NS	-0.68 NS	2.36*	**0.83****
IGP	**TOI**	**1.88NS**	**3.87****	**1.30NS**	**0.71NS**	**0.92NS**	**1.76****
	TII	**1.80****	**1.27****	**0.83***	**1.17NS**	**0.15NS**	**1.64****
	TFPI	**0.08NS**	**2.57***	**0.46NS**	**-0.46NS**	**0.77NS**	**0.12NS**

N.B.: * means < $p_{0.05}$ level, ** means < $p_{0.01}$ level, NS = non-significant

Likewise, Wheat TFP has exhibited a disheartening picture where a diminishing trend was registered with significant negative growth in Trans-Gangetic plain (Punjab and Haryana) as well as Upper and Middle Gangetic plain (Uttar Pradesh and Bihar) barring West Bengal. The results fully support what have done previously by Kumar and Mruthyunjaya (1992); Kumar *et al*. (2004); and Sekar *et al*. (2012) that TFP growth of Wheat is decelerating in IGP of India and large areas under crops in a number of districts are showing clear signs of un-sustainability. Giving a close look to each decade, TII has surpassed TOI for the state Punjab and Haryana while the later state has gained in TFP during 1980's. Uttar Pradesh has featured faster rate of change in TOI as compared to TII for the first and second decade while in case of Bihar, there is a significant regain in the growth rate of TOI during third decade. Wheat was not a predominant crop cultivated in the state West Bengal (Kumar *et al*. 2000) and thus TFP performance was not much considerable in the past decades and its prominence is increasing as the year passes.

Table 2: Exponential growth rates of Indices for Wheat in IGP of India (1970-20):

States	Index	1970-80	1980-90	1990-00	2000-10	2010-20	1970-20
Punjab	TOI	2.49**	2.75**	2.05**	0.19 NS	0.80 NS	**1.66****
	TII	3.09**	2.88**	3.00**	2.00**	1.91**	**2.41****
	TFPI	-0.58 NS	-0.13 NS	-0.92 NS	-1.78*	-1.08 NS	**-0.74****
Haryana	TOI	3.26*	4.12**	1.51**	0.90 NS	0.02 NS	**2.10****

	TII	8.10**	2.86**	2.90**	2.76**	0.55 NS	**3.08****
	TFPI	-4.48**	1.22 NS	-1.36 NS	-1.81 NS	-0.53 NS	**-0.95****
Uttar Pradesh	TOI	3.15 NS	2.74**	2.10**	1.12 NS	1.92 NS	**2.09****
	TII	1.16 NS	1.53*	2.59**	4.29**	1.94*	**2.13****
	TFPI	1.96 NS	1.19 NS	-0.47 NS	-3.04	-0.02 NS	**-0.04 NS**
	TOI	-2.71 NS	2.21**	2.59*	1.22 NS	3.34 NS	**1.43****
Bihar	TII	0.01 NS	2.36 NS	-0.21 NS	2.35**	1.84**	**1.72****
	TFPI	-2.73 NS	-0.15 NS	2.81*	-1.11 NS	1.48 NS	**-0.29***
	TOI	-2.71 NS	-2.49 NS	0.47 NS	2.47*	0.02 NS	**0.84****
West Bengal	TII	0.01 NS	0.07 NS	-0.40 NS	2.17**	-2.15*	**0.16***
	TFPI	-2.73 NS	-2.56 NS	0.86 NS	0.29 NS	2.22 NS	**0.68****
	TOI	**0.65NS**	**1.84***	**1.74****	**1.17NS**	**1.21NS**	**1.62****
IGP	**TII**	**2.43****	**1.94****	**1.56****	**2.71****	**0.80****	**1.90****
	TFPI	**-1.74NS**	**-0.09NS**	**0.17NS**	**-1.50NS**	**0.41NS**	**-0.27****

N.B.: * means < $p_{0.05}$ level, ** means < $p_{0.01}$ level, NS = non-significant

Overall, RWCS has being threatened by declining trend in TFP for the IGP of India over several decades (Kumar *et al*. 2000; Hobbs *et al*. 2003; Jat *et al*. 2009; Saharawat *et al*. 2010; Chauhan *et al*. 2012; Sekar *et al*. 2012; Kumar *et* al. 2018; Bhatt *et. al*. 2019; Srinivasrao *et al*. 2019; Bhatt *et al*. 2020; Bhatt *et al*. 2021; Dhanda *et al*. 2022). The continuous sequential cropping has created an enormous problem of stagnation in Rice-Wheat productivity over IGP decade after decade (Imtiaz *et al.* 2012). A rational thinking is very much welcomed to diagnose the problems, pros and consequences that could explain the cause-and-effect scenario of the system. Punjab and Haryana have registered a significant negative growth in TFP while other three states have featured stagnancy. Punjab being the heart of foodgrains producing state of India has experienced a gradual decrease in TOI over decades and third decade onwards TII has surpassed TOI resulting a negative growth in TFP. Haryana has registered positive move in TOI over 1970's but fail to retain its performance later on. Uttar Pradesh and Bihar have performed significantly well regarding TFP growth where barring fourth decade, all other decades have shown prominence in TOI over TII. West Bengal has shown remarkable significant recovery of TFP under RWCS in the fifth decade (2.17 per cent) as Wheat cultivation is gaining prominence at later phase (2010-11 to 2019-20) (Kumar *et al*. 2000).

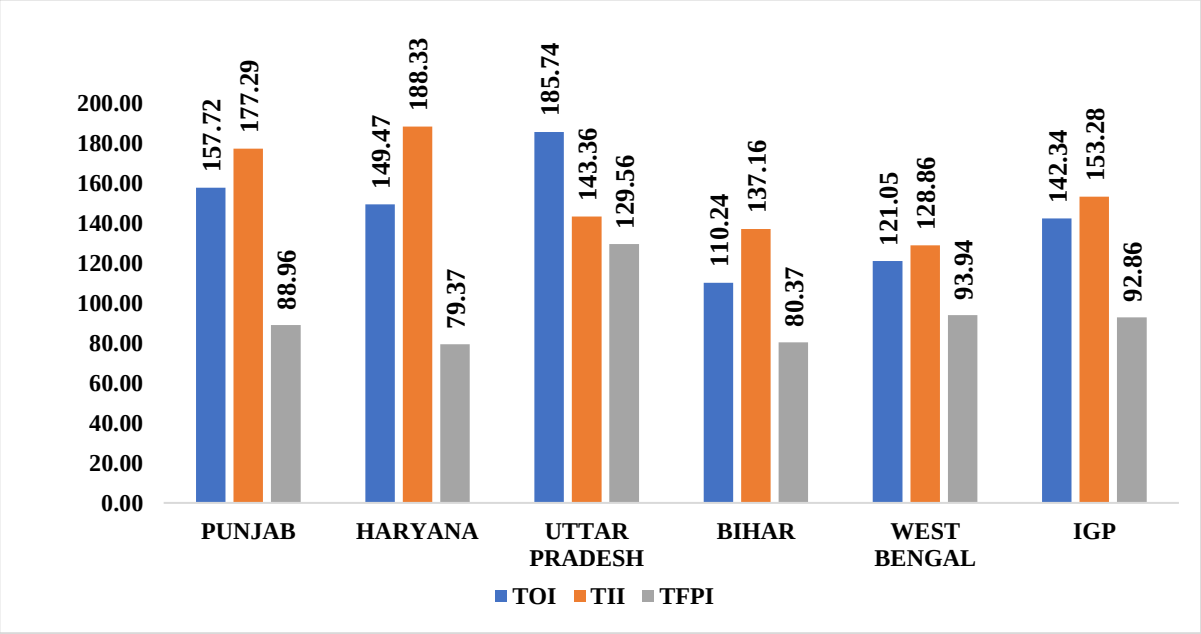
Table 3: Exponential growth rates of Indices for Rice-Wheat Cropping System (RWCS) in IGP of India (1970-20):

States	Index	1970-80	1980-90	1990-00	2000-10	2010-20	1970-20
	TOI	3.62**	1.86**	1.09NS	1.02**	0.91 NS	**1.48****
Punjab	TII	0.94**	1.54*	2.56**	1.23 NS	2.14**	**2.30****
	TFPI	0.94NS	0.31NS	-1.44**	-0.21 NS	-1.21 NS	**-0.80****
	TOI	3.99*	2.27*	-0.36 NS	1.16*	0.24 NS	**1.47****
Haryana	TII	3.22**	2.85**	1.44*	2.10*	-0.22 NS	**2.74****
	TFPI	0.74 NS	-0.56 NS	-1.77*	0.24 NS	0.47 NS	**-1.24****
	TOI	2.14 NS	3.88**	2.29**	0.90 NS	1.69 NS	**2.24****
Uttar Pradesh	TII	1.01 NS	1.04 NS	1.20**	3.02**	0.87 NS	**1.68****
	TFPI	1.12 NS	2.81*	1.08*	-2.05 NS	0.82 NS	**0.55****
Bihar	TOI	-2.20 NS	3.32*	3.36*	0.49 NS	2.29 NS	**1.67****

	TII	1.17*	2.49*	-0.05 NS	1.71*	1.24**	**1.51****
	TFPI	-3.33*	0.81 NS	3.42*	-1.20 NS	1.04 NS	**0.16** NS
	TOI	-0.31 NS	1.49 NS	0.91 NS	1.26**	0.49 NS	**1.37****
West Bengal	TII	1.90*	0.46*	1.14 NS	1.60**	-1.64*	**0.91****
	TFPI	-2.17 NS	1.02 NS	-0.22 NS	-0.34 NS	2.17*	**0.45****
	TOI	**1.42**NS	**2.56****	**1.45****	**0.97**NS	**1.12**NS	**1.64****
IGP	TII	**1.99****	**1.67****	**1.25****	**1.93****	**0.47***	**1.83****
	TFPI	**-0.56**NS	**0.87**NS	**0.20**NS	**-0.95**NS	**0.65**NS	**-0.18***

N.B.: * means < $p_{0.05}$ level, ** means < $p_{0.01}$ level, NS = non-significant

Fig1: State-wise Geometric Mean of TOI TII & TFPI indices of RWCS in IGP India (1970-20)



Price effect for Rice and Wheat would play a significant role in computing TFP for a longer period of time. As Divisia Tornqvist-Theil superlative indices consider the value of total output to the value of total factor inputs, price will always play a significant major role. There was a paramount increase in Farm Harvest Price (FHP) of Rice and Wheat over Indo-Gangetic states of India as FHP index of Rice for Punjab has increased from 100.0 unit in 1970-71 to 1713.89 unit in 2019-20 with a 7.24 per cent exponential growth rate. Similar trend was observed for Wheat where FHP index increases from 100.0 to 1698.89 units with a 6.85 per cent growth. Maximum FHP growth for Rice and Wheat was registered (9.06 and 6.88 per cent respectively) in Haryana. While looking into the change in total cost of production incurred for Rice and Wheat cultivation per unit land across Indo-Gangetic states of India, maximum change has been observed in the state of West Bengal (8.49 per cent) followed by Uttar Pradesh (8.40 per cent). Thus, cost of production always surpasses the price effect of output that would be one of the major reasons for declining TFP as input use become more or less unchanged over the five

decades of farming practice. The International Rice Prices have declined markedly since 1995 while prices of production inputs have increased (Calpe 2003).

To avoid the controversy of price effect on production, total value product and total cost incurred, output oriented DEA-Malmquist Indices have also been applied to judge the extent of technical and efficiency change that would jointly complies the overall technological change. It was registered unanimously that, TFP of Rice, Wheat and RWCS have declined in IGP of India as a whole. However, the entire change in TFP was guided by the technical substitution of quality inputs and not by the efficiency of the farmers in regards to knowledge and perception gaining in farming. This word has a conformity with the previous study of Foster and Rosenzweig (1996); Acharya (1997); Desai and Namboodire (1997); Kaliranjan and Shand (1997); Arnade (1998); Munshi (2004) and Bhushan (2005) that though the efficiency change by the farming community of India is lacking importance, this would be the prime source to enhance TFP growth in long term scenario that could sustain the overall livelihood of agricultural farm-families. The progressivity of the Indian farmers particularly for the state of Punjab and Haryana were likely to be more as compared to Uttar Pradesh, Bihar and West Bengal to adopt new technology that leads to regional disparity within IGP states (Kumar *et al*. 2000; Bhushan 2005; Sekar *et al*. 2012).

Table 4: State wise Malmquist indices for Rice, Wheat and Rice-Wheat Cropping System (RWCS) in IGP of India (1970-20)

Crop	State	EFFCH	TECHCH	TFPCH
Rice	Punjab	1.000	1.030	1.030
	Haryana	1.000	1.015	1.015
	Uttar Pradesh	1.000	1.021	1.021
	Bihar	1.000	0.946	0.946
	West Bengal	1.000	0.892	0.892
	Mean	**1.000**	**0.979**	**0.979**
Wheat	Punjab	1.000	1.042	1.042
	Haryana	1.000	0.999	0.999
	Uttar Pradesh	1.005	0.985	0.990
	Bihar	1.000	0.994	0.994
	West Bengal	1.000	0.945	0.945
	Mean	**1.001**	**0.992**	**0.993**
Rice-Wheat	Punjab	1.000	1.042	1.042
	Haryana	1.000	0.998	0.998
	Uttar Pradesh	1.000	1.017	1.017
	Bihar	1.000	0.975	0.975
	West Bengal	1.000	0.851	0.851
	Mean	**1.000**	**0.974**	**0.974**

Multiple step-wise regression between TFP and various explanatory factor inputs under Rice, Wheat and RWCS in Indo-Gangetic states of India have been computed subsequently to

identify the key contributor responsible for technological change. The Interest on Working Capital has been identified as the major factor contributing a significant negative impact for both the states of Trans Gangetic Plains (Punjab and Haryana) indicating an awful investment decisions by the farmers. Eroding the profit level of farmers in such a way is a disincentive to the farmers to invest more and hence eventually results in reduction of yield (Sekar *et al*. 2012). There was a striking feature observed while computation of input items for Punjab and Haryana, that these two states have followed direct seeded rice instead of transplanted rice as their common practices (CGIAR 2023). In Middle Gangetic Plain (Uttar Pradesh) poor quality of seed use has been resulted a significant negative influence on the productivity of Rice. Traditional cultural practices are still prevailing in the states of Upper and Lower Gangetic Plains (Bihar and West Bengal) and thus leading to depressing trends in the overall productivity of Rice as puddling being still the common practice before transplanting rice to main field (Dhillon *et al*. 2021). Intensive tillage and puddling for rice resulted the development of hard plough pan, decreased input use efficiency, declined yields, hiked insect-pest outbreak and global warming (Nawaz *et al*. 2019). Looking into Wheat, employment of efficient human labour has become the sole contributor with a significant positive impact on the TFP change for both the states of Punjab and Bihar. At the onset of mechanization in agriculture particularly for the state of Punjab and Haryana, human labour use has been reduced periodically as compared to other states of India. A very few studies have revealed that the ownership of machinery is also significantly influenced by the factors such as size of landholding, access to irrigation and access to institutional credit. The pattern of investment and ownership of machinery has important implications on the profitability of farming (Sarkar 2020). The north-western parts of India, is mostly depended on groundwater for irrigation (Ambast *et al*. 2019, Nawaz *et al*. 2019) and excessive exploitation of groundwater has led to set a question against sustainability of the wheat production in the state Haryana (Humphreys and Gaydon, 2015; Bhatt *et al*. 2020). For the state Uttar Pradesh no single factor can be recognized for having a significant impact on TFP of Wheat. Dominancy of Bullock labour with lack of mechanization in the state West Bengal has confirmed a significant negative impact upon overall productivity of wheat.

Punjab is well known for its progressive labour base and thus it has paid a significant positive impact on the RWCS. Declining ground water tables in recent days has resulted a significant negative influence on the overall productivity in Haryana. Adequate amount of inorganic fertilizer application leads to a positive impact on overall productivity in Uttar Pradesh. The states of Upper and Lower Gangetic Plains (Bihar and West Bengal) are reluctant to adopt

mechanization and thus dominancy of bullock labour use has resulted significantly negative trends and thus it needs to change the conventional practices for achieving overall sustainability in the region (Timsina and Connor 2001; Bhatt *et al*. 2020).

Table 5: Step-wise Multiple log-linear regressions between change in TFP over change in various inputs use in IGP of India (1970-20)

Crop	States	Regression Equation	Parameters
Rice	Punjab	$Y=5.340(-)0.149X_9^{**}$	X_9: INTWC
		$Y=4.682(-)0.175X_9^{**}+0.155X_2^{*}$	X_2: Fertilizer use
	Haryana	$Y=5.593(-)0.210X_9^{**}$	X_9: INTWC
	Uttar Pradesh	$Y=6.870(-)0.513X_1^{**}$	X_1: Seed
	Bihar	$Y=4.855(-)0.071X_7^{**}$	X_7: Animal labour use
	West Bengal	$Y=5.426(-)0.158X_7^{**}$	X_7: Animal labour use
		$Y=5.118(-)0.105X_7^{**}+0.013X_5^{*}$	X_5: Machine labour use
		$Y=8.766(-)0.012X_7^{NS}+0.034X_5^{**}$ (-)$0.596X_8^{*}$	X_8: Human labour use
		$Y=9.020+0.036X_5^{**}$ (-)$0.642X_8^{**}$	X_3: Manure
		$Y=8.342+0.030X_5^{**}$(-)$0.485X_8^{**}$ (-)$0.125X_3^{**}$	
Wheat	Punjab	$Y=3.091+0.233\ X_8^{**}$	X_8: Human labour use
		$Y=1.819+0.310\ X_8^{**}+0.161\ X_2^{**}$	X_2: Fertilizer use
		$Y=1.775+0.151\ X_8^{**}+0.507\ X_2^{**}$(-)$0.121\ X_5^{**}$	X_5: Machine labour use
	Haryana	$Y=5.021(-)0.121\ X_4^{**}$	X_4: Irrigation
		$Y=4.513(-)0.197\ X_4^{**}+0.205\ X_2^{**}$	X_2: Fertilizer use
		$Y=4.760(-)0.216\ X_4^{**}+0.180X_2^{**}$(-)$0.047\ X_3^{**}$	X_3: Manure
	Uttar Pradesh	$Y=3.083(-)0.266\ X_1^{NS}+0.679\ X_2^{NS}+0.020\ X_3^{NS}$ (-)$0.067\ X_4^{NS}+0.254\ X_5^{NS}$ (-)$0.010\ X_6^{NS}$ (-)$0.026\ X_7^{NS}+0.135\ X_8^{NS}$ (-)$0.471\ X_9^{NS}$	X_1: Seed X_2: Fertilizer use X_3: Manure X_4: Irrigation X_5: Machine labour use X_6: Plant protection chemicals X_7: Animal labour use X_8: Human labour use X_9: INTWC
	Bihar	$Y=2.985+0.211\ X_8^{**}$	X_8: Human labour use
		$Y=0.317+0.588\ X_8^{**}+0.048\ X_5^{*}$	X_5: Machine labour use
	West Bengal	$Y=5.317(-)0.143\ X_7^{**}$	X_7: Animal labour use
Rice-Wheat	Punjab	$Y=2.413+0.307\ X_8^{**}$	X_8: Human labour use
		$Y=0.204+0.342\ X_8^{**}+0.409\ X_1^{**}$	X_1: Seed
	Haryana	$Y=5.773(-)0.180\ X_4^{**}$	X_4: Irrigation
		$Y=4.676(-)0.262\ X_4^{**}+0.300\ X_2^{**}$	X_2: Fertilizer use
	Uttar Pradesh	$Y=3.726+0.216X_2^{**}$	X_2: Fertilizer use
		$Y=1.779+0.924X_2^{**}$(-)$0.317X_9^{**}$	X_9: INTWC
		$Y=3.668+0.410X_2^{NS}$ (-)$0.472X_9^{**}+0.241\ X_5^{*}$	X_5: Machine labour use
		$Y=5.109(-)0.533X_9^{**}+0.391X_5^{**}$	X_1: Seed
		$Y=9.692(-)0.515X_9^{**}+0.374X_5^{**}$ (-)$0.892X_1^{*}$	
	Bihar	$Y=4.476(-)0.019X_7^{*}$	X_7: Animal labour use
	West Bengal	$Y=5.145(-)0.105X_7^{**}$	X_7: Animal labour use

Sources of TFP change in IGP India

The gradual decline in TFP of RWCS across IGP of India over last fifty years have raised several queries that could threaten the sustainability of Indian farming and overall livelihood of the farm-family as well. However, the extent of TFP is influenced by several socio-economic

factors and to identify the key factor 31 socio-economic indicators have been included. The economic indicators considered were Gross value added at constant prices, per capita Net National Income (NNI) at factor cost, Gross domestic capital formation as percentage of GDP, Wholesale price index, Consumption of coal and lignite, crude oil and electricity, Foreign trade export and import, Public expenditure (Central and State) on agricultural research and development (R&D), GDP in agriculture and allied sector, Public expenditure in Rural Development, Irrigation and Flood Control, Energy, Industry, Transport and Communication, Science Technology and Innovation, General Economic and Social Services, Irrigation, Employment of Agricultural Labourer and Agricultural credit scenario; whereas the social indicators like population, birth rate, death rate, life expectancy at birth and education were taken into matter.

Overall multiple step-wise log-linear regression of TFP for RWCS with 31 socio-economic indicators have revealed that rural electrification has a positive impact behind TFP change over five decades while per capita NNI at factor cost exerts a negative impact over declination in TFP. Other factors have not much influence on change in TFP over time. Punjab has featured negative impact of Gross value added over TFP change where a gradual decline in contribution of agriculture on GDP has been observed (Agriculture sector contributes around 55% of GDP in 1950-51, which has come down to 14% in 2011-12 and again increased up to 17.8% in 2019-20 and further 19.9% in 2020-21). Haryana has a positive impact of high birth rate followed by a sharp increase (7.79%) in wholesale price index (WPI) on TFP RWCS resulting remunerative prices for the producer farmer. Lack of foreign trade would be the major reasons behind the stagnancy in TFP RWCS for the state Haryana and Uttar Pradesh as well. Lack of public expenditure on social welfare services is another major factor behind the stagnancy in TFP whereas WPI followed by Gross Domestic Capital Formation have a significant positive impact behind TFP change in Uttar Pradesh as well. Surplus of labour resulting disguised unemployment would be the major cause behind the change in TFP for Bihar as lack of mechanization prevails with significant negative impact of animal labour. West Bengal has shown a positive impact of per capita NNI on TFP R-W with a lack of capital formation and resource generation.

Table 6: Step-wise Multiple log-linear regressions between change in TFP over change in various socio-economic indicators across states of IGP in India (1970-20)

States	Regression Equation	Parameters
Punjab	$Y = 6.390\ (-)\ 0.131X_1^{**}$	X_1: Gross value added at constant prices

Haryana	$Y = 2.445 + 0.561X_{11}^{*}$	X_{11}: Birth rate
	$Y = 0.249 + 1.048X_{11} + 0.536X_{4}^{*}$	X_4: Wholesale Price Index
	$Y = 1.794 + 0.709X_{11} + 0.178X_{4}^{*}$ (-) $0.053X_{8}^{*}$	X_8: Aggregate Export
Uttar Pradesh	$Y = 6.424$ (-) $0.118X_{26}^{*}$	X_{26}: Public expenditure on social service
	$Y = 9.209$ (-) $0.289X_{26}^{*}$ (-) $0.051X_{8}^{*}$	X_8: Aggregate Export
	$Y = 8.025$ (-) $0.213X_{26}$ (-) $0.148X_{8}^{*} + 0.305X_4$	X_4: Wholesale Price Index
	$Y = 1.042 + 0.089X_{26}$ (-) $0.162X_{8}^{*} + 0.557X_4 + 0.629X_3$	X_3: Gross Domestic Capital Formation
	$Y = 2.916$ (-) $0.163X_{8}^{*} + 0.497X_4 + 0.496X_3$	
Bihar	$Y = 4.302 + 0.013X_{28}^{**}$	X_{28}: Total cultivator plus Agricultural labourer
West Bengal	$Y = 3.338 + 0.120X_{2}^{*}$	X_2: Per capita Net National Income at factor cost at constant prices
	$Y = 3.720 + 0.013X_{2}^{*}$ (-) $0.145X_3$	X_3: Gross Domestic Capital Formation
IGP	**$Y = 5.087$ (-) $0.055X_{2}^{*}$**	**X_2: Per capita Net National Income at factor cost at constant prices**
	$Y = 5.279$ (-) $0.095X_{2}^{*} + 0.035X_{7}^{*}$	**X_7: Electrification**

A striking feature has been registered that public investment in R&D wing has not much significance with TFP and this could be contradicted by various economists, researchers, bureaucrats and scholars as well. For the past fifty years, the TFP of RWCS in IGP of India have negatively correlated with public investment in R&D wing (-0.41), followed by negative impact on agricultural GDP (correlation coefficient found to be -0.39). Even, the introduction of Rashtriya Krishi Vigyan Yojona (RKVY) scheme, a multidisciplinary project established to all the Central and State Agricultural Institutions since 10^{th} five-year plan in order to ensure an institutional and structural change in agriculture to various corner of the country have not much significance on TFP. Again, public investment in agriculture and rural development has exerted a negligible impact on TFP change over decades.

Table 7: Correlation between TFP and Public Expenditure on Agriculture and Rural Development in IGP India

	TFP_{IGP}	**GE_RD**	**GDP_Agri**	**PE_Agri**	**PE_Rural_Dev**
TFP_{IGP}	1.00				
GE_RD	-0.41	1.00			
GDP_Agri	-0.39	0.98	1.00		
PE_Agri	-0.05	-0.51	-0.61	1.00	
PE_Rural_Dev	-0.01	-0.29	-0.36	0.87	1.00

N.B.: TFP_{IGP}: Total factor productivity in Indo-Gangetic Plain
GE_RD: Government Expenditure on Research and Development
GDP_Agri: Gross Domestic Product of Agriculture
PE_Agri: Public Expenditure on Agriculture
PE_Rural_Dev: Public Expenditure on Rural Development

Conclusion:

The entire study attempts to register the extent of technological change in RWCS across Indo-Gangetic belt of India and to identify the major factors and sources responsible for TFP change over time. However, the study is a continuation of previous works in order to ensure that the TFP of RWCS in IGP of India is stagnating and declining over time. The uniqueness of this study is that the authors try to accomplish the performance of Rice, Wheat and RWCS separately under IGP of India over last five decades with a modest attempt to analyse TFP with and without constant returns to scale restrictions (Divisia Tornqvist-Theil index model with constant return to scale and output oriented DEA-Malmquist indices without constant return to scale) and correlate their findings with various driving sources that could guide the entire structural and institutional change in agriculture. However, it was registered that previously not much work has been done on the similar concept while Shanmugan and Prakash (2018); too have attempted to evaluate the combined effects of conventional and non-conventional factors and notice a falling trend in TFP with constant returns to scale restriction and observing no conclusive linear trend in TFP without constant returns to scale (CRS) restriction in Indian agricultural scenario. Rising cost of production with mounting price of agricultural inputs and wage rate over last fifty years also would be a major reason of declining TFP in Indian agriculture. Overuse of chemical and inorganic fertilizers, insecticides, fungicides and herbicides could be the main reason behind saturation in agricultural productivity moving beyond the maximum regime resulting negative slope in marginal physical product and stagnation in TFP growth.

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