Policy Paper 44

From Research to Impact

Payoffs to Investment in Agricultural Research and Extension in India

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Foreword

By 2047, India is envisioned to be a developed country with a population of more than 1.6 billion. As the population increases and higher incomes drive changes in food consumption patterns, demand for food and non-food commodities will increase significantly. Compared to staple foods, demand for high-value food commodities will be much larger. At the same time, prospects for increasing production through area expansion are not bright, and the intensification of the existing agricultural land will come under severe pressure from the growing scarcity of water and energy and the increasing frequency of extreme climate events.

Research in and for agriculture has significant potential to address the current and future challenges to transforming agri-food production systems as more productive, efficient, and sustainable. In India, most research in agriculture and allied activities is carried out in public-sector institutions. Agricultural R&D, however, remains underinvested. In 2020-21, the country spent about 0.54% of agricultural gross domestic product on research and 0.11% on extension, much less than their corresponding global levels.

Nevertheless, there is a strong justification for more investment in agricultural R&D. Every rupee spent on research pays back Rs 13.85, and on extension, Rs 7.40. Hence, by 2030, investment in R&D should be raised to at least one percent of the agricultural gross domestic product. Importantly, it should be accompanied by revamping of the research agenda, considering the likely demand for different food and non-food commodities, the current and future challenges, and opportunities. This study suggests more resources for research on livestock, fisheries, natural resource management, and climate adaptation and mitigation, and bridging the regional R&D gaps.

The past is the guide to the future. Investment in R&D made today will decide the future course of agricultural development. The evidence presented in this study are of significant importance to research administrators and policymakers in taking informed decisions regarding investment in agricultural R&D and its prioritization for the smooth transformation of agri-food systems. I congratulate the authors for this timely publication.

Himanshu Pathak
Secretary, Department of Agricultural Research and Education,
Government of India
&
Director General, Indian Council of Agricultural Research

Preface

Agricultural research, innovations, knowledge, and information are crucial for addressing the current and future challenges to the agri-food system transformation, especially in countries like India that face acute resource constraints of land, water, and energy, and are highly exposed to climate risks.

Agricultural research, possesses significant potential to overcome land, water, and energy constraints and enhance farm productivity and resilience to climate change. It is one of the most efficient pathways to ensure nation's food security, combat malnutrition, and reduce poverty. In the past, India immensely benefitted from public-funded research in rich countries. However, the landscape of agricultural research and innovations is gradually shifting in the domain of private sector, which is attuned to market opportunities. On the other hand, several developing countries dominated by poor smallholder farmers are still struggling to achieve self-sufficiency in food. Therefore, governments must invest more in research in and for agriculture.

This study investigates the level and trend in research and extension investments and assesses economic returns thereupon at the aggregate and sub-sector levels. It finds underinvestment in agricultural R&D in India relative to the global average, and a slowdown in its growth. It also reports a significant imbalance in resource allocation across sub-sectors or disciplines. Nevertheless, the payoffs to investment in research and extension are quite significant. Such information is crucial for research administrators and policymakers to make informed decisions regarding the adequacy of investment in agricultural R&D and its prioritization across disciplines, commodities, and regions to derive maximum economic, social, and environmental benefits from the investment.

In the course of this study, we have immensely benefited from the comments and suggestions of several professionals. We sincerely thank Dr Himanshu Pathak, Secretary, Department of Agricultural Research and Education, Government of India & Director General, Indian Council of Agricultural Research, for his motivation and suggestions. Dr P K Joshi, former Director (South Asia), International Food Policy Research Institute, New Delhi;

Dr P Kumar, former Head, Division of Agricultural Economics, Indian Agricultural Research Institute, New Delhi; Dr Suresh Pal, former Director, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi; and Dr Kamal Vatta, Professor, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana provided critical comments and suggestions on an earlier draft of this paper. We have also benefited from interactions with Dr Seema Bathla, Jawaharlal Nehru University, New Delhi, and our colleagues Dr Jaya Jumrani, Dr Raka Saxena, and Dr Shiv Kumar. We are grateful to all of them. Financial assistance for this study from the Indian Council of Agricultural Research is gratefully acknowledged.

Authors

Executive Summary

Over the past five decades, science, technology, and innovations in and for agriculture, supported by massive investments in irrigation, markets, road and communication networks, institutions (extension and credit), and incentives (input subsidies and output price support), transformed India from a food-insecure to a food-surplus nation. Nevertheless, the need to produce more food remains as urgent as ever. By 2047 — the centenary year of its independence — the country's population will also cross the 1.6 billion mark, and half of it will live in cities and towns. Further, by then India is envisioned to be in the league of developed countries. To realize this vision, the economy must grow about 8% annually. Thus, people will be more affluent, demanding more diverse and nutritious foods. By 2047, overall food demand is expected to be more than double the current demand but with significant differences in demand growth of different food commodities. The demand for high-value food commodities such as fruits, vegetables, milk, meat, egg and fish will increase faster.

On the other hand, agri-food production systems will come under a confluence of several biotic and abiotic pressures, including the growing scarcity of land, water, and energy, increasing threats of climate change, insect-pests, and diseases, and degradation of natural resources, biodiversity, and the environment amidst the shrinking land frontiers and growing pressure to absorb additional workforce. Indian agriculture is dominated by smallholders cultivating tiny pieces of land not exceeding one hectare, and they will suffer the most from such challenges. Hence, future growth in agriculture must be driven by science, technology, innovations, knowledge, and information. Therefore, more investment in agricultural research is necessary for technological breakthroughs to keep agriculture energized to move on a higher and more sustainable growth trajectory.

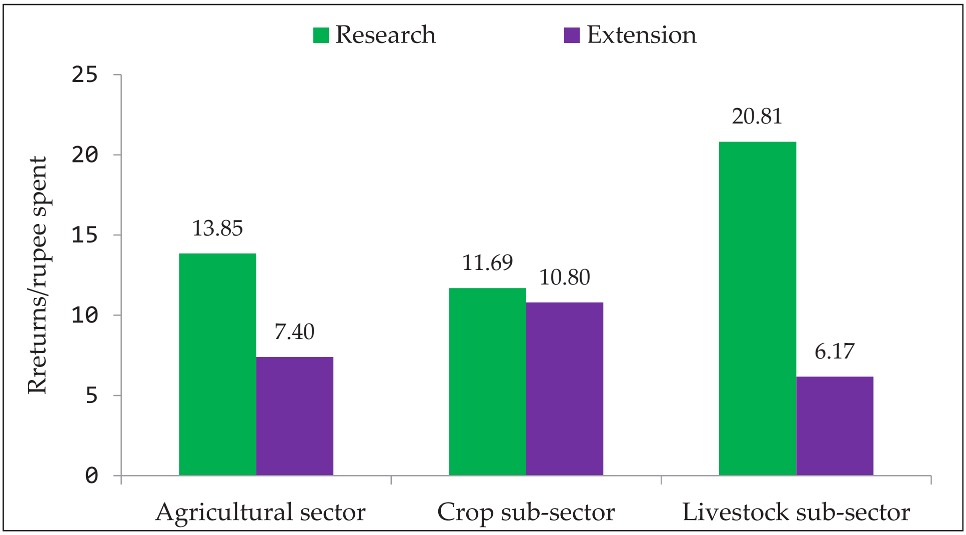
This study has examined the behaviour of R&D investments in Indian agriculture at the aggregate and sub-sector levels and estimated returns on these. Such information is of significant utility for decision-makers to justify public investment in R&D and its prioritization across disciplines, commodities, and regions to derive maximum economic, social, and environmental benefits.

The following are the key conclusions of this study:

Investment in agricultural R&D is highly productive: Every rupee spent on agricultural research (including education) pays off Rs 13.85 (Figure 1). The payoff to investment in agricultural extension is also quite attractive, Rs 7.40.

Payoffs to investment in R&D differ across sub-sectors of agriculture: At a similar level of spending, animal science research is almost twice as productive as crop science research. One rupee spent on animal science research pays off Rs 20.81 compared to Rs 11.69 on crop science research. On the contrary, the payoff to investment in crop extension is relatively more (Rs 10.80) than that in livestock extension (Rs 6.17).

Figure 1. Payoff to investment in agricultural R&D



Agricultural R&D is primarily public-funded. The bulk of the research in agriculture and allied sciences is carried out in public-sector institutions financed by the central and state governments through their budgets. From 2011 to 2020, public-sector investment comprised 92% of the total R&D investment, and 63% of it came from states. The private sector accounted for about 8% of the total.

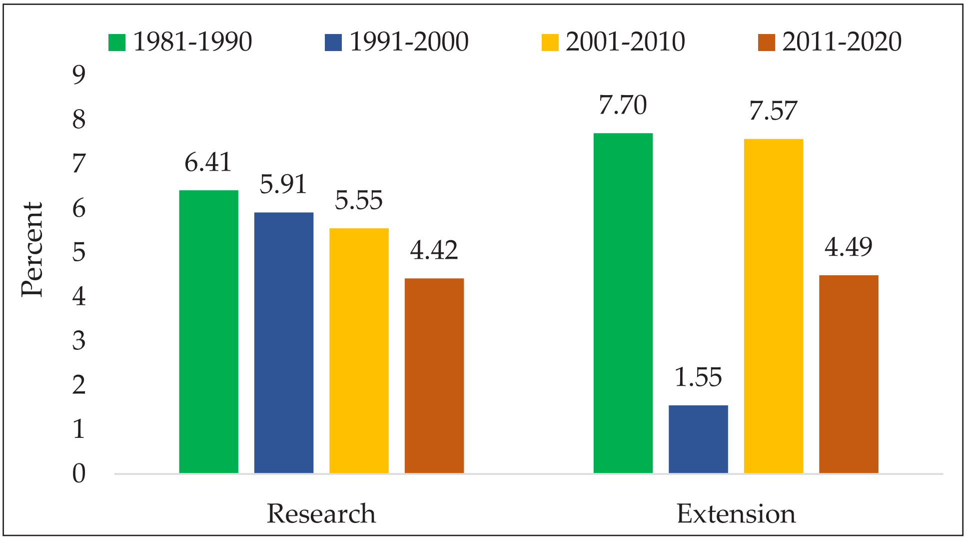
Agricultural R&D has remained underinvested: Despite the significant increase in spending on R&D, its intensity — the proportion of agricultural gross domestic product (AgGDP) spent on R&D — has remained low. From 2011 to 2020, India on average spent 0.61% of its AgGDP on agricultural research, which is about two-thirds of the global average (0.93%) and much less than 1-5% by several developed countries.

The proportion of AgGDP spent on agricultural extension is estimated at 0.16%. Yet there are significant inter-year fluctuations. In 2020-21, India spent 0.54% of its AgGDP on research and 0.11% on extension. Notably, India has not reached the research intensity of 0.77% that rich countries had in the early 1960s.

Growth in R&D investment has slowed: The annual growth in investment in agricultural research has slowed down from 6.4% during 1981-1990 to 4.4% during 2011-2020 (Figure 2); the slowdown has been faster in the case of central government and private-sector investment. The growth in investment in extension has been cyclical, with ridges and troughs. For example, from 2011 to 2020, it decelerated to 4.5% from 7.6% during 2001-2010.

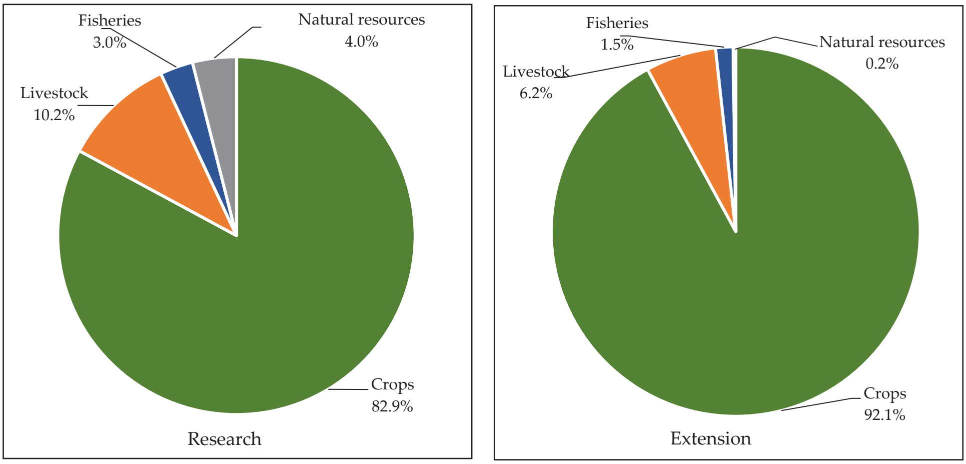
Private-sector investment has no crowding-out effect: The public and private investments in agricultural research are highly correlated, suggesting complementarity rather than competition between the public and private sectors.

Figure 2. Annual growth in investment in agricultural R&D



Agricultural R&D has remained crop-centric: Research and extension investments have excessively concentrated on crops. From 2011 to 2020, crops shared 83% of the total research investment and 92% of the extension investment (Figure 3). Note that this pattern of resource allocation has remained almost the same over time, indicating a lack of dynamism in resource allocation aligning with emerging challenges and opportunities in agriculture.

Figure 3. Composition of agricultural research and extension investment



There are significant regional variations in R&D investment: From 2011 to 2020, Rajasthan, Odisha, Madhya Pradesh, West Bengal, and Uttar Pradesh, which account for about 43% of the country's net sown area, spent less than 0.25% of their AgGDP on agricultural research and extension. On the other hand, the hill states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand, and Assam, Bihar, and Kerala spent more than 0.80%.

By 2047, India's population will surpass the 1.6 billion mark, with a strong urbanization trend. It is inspiring to note that, by then, India is envisioned to be in the league of developed countries. To realize this vision, the economy must grow about 8% annually. Thus, people will be more affluent and demand more diverse, nutritious, and value-added or processed foods of both plant and animal origin. The demand for agricultural produce for feed, fibre, and fuel is also expected to increase considerably.

Concurrently, agricultural production systems will come under several biotic and abiotic pressures. For the past three decades, India's net sown area has stagnated at around 140 million hectares, implying limited prospects of agricultural growth through the extensification of the existing land. At the same time, its intensification will be constrained by the growing scarcity of water and energy. Besides, the increasing frequency of extreme climate events such as droughts, floods, and heat waves will cause significant damage to agricultural production.

Nevertheless, science, technology, innovations, and information have considerable potential to address multiple challenges, including improving agricultural productivity and resilience to climate change, enhancing resource-use efficiency, reducing the cost of production, lowering pre- and post-harvest losses, and preserving natural resources and biodiversity. Therefore, an increase in investment in agricultural research is crucial for higher, efficient, sustainable, and inclusive growth of agriculture.

The findings of this study provide important insights into the role of agricultural research, innovations, and information in transforming agri-food systems. These can serve as important feedback for decision-makers to justify public investment in agricultural R&D and its prioritization across disciplines, commodities, and regions to derive maximum economic, social, and environmental benefits from the investment.

The following are important implications of the above findings:

Enhance public investment in agricultural research: A generic but one of the most important recommendations is to increase public-sector investment in research in agriculture consistently. In the short run, say by 2030, it should be raised to match the global average of about one percent of AgGDP.

Facilitate private-sector investment in agricultural research: Both central and state governments should create and foster an environment for private and philanthropic investment in agricultural research. The private sector can develop its research capacity or financially support public-sector research through collaborations and partnerships. Agricultural research involves significant fixed costs and a long gestation period. India's national agricultural research system is pretty well-developed in infrastructure and human resources, which can be leveraged to strengthen public-private partnerships and collaborations for research.

Prioritize investment in agricultural research: Agricultural research has focussed comparatively more on crops and less on livestock, fisheries, and natural resources. Given the more egalitarian distribution of livestock and fast-growing demand for animal-source foods, the social payoffs (i.e., reduction in poverty and malnutrition) from increased spending on animal science research are likely to be quite significant. Further, looking towards the increasing threat of climate change and unabated quantitative and qualitative deterioration of natural resources and biodiversity, more research is needed on the conservation of natural resources and biodiversity, as well as climate adaptation and mitigation.

Bridge regional gaps in R&D: Odisha, Rajasthan, Madhya Pradesh, West Bengal, and Uttar Pradesh spend significantly less on R&D. Conditional upon a sustained increase in investment in R&D: these states can drive future growth in Indian agriculture. On the other hand, Himachal Pradesh, Jammu & Kashmir, Uttarakhand, Kerala, Bihar, and Assam, which spend relatively more on research, need to harness the potential benefits of research by improving the infrastructure and institutions that facilitate the adoption of technologies, and natural resource management and agronomic practices.

Strengthen research-extension-farmer linkages: Potential gains from investment in research may remain subdued if the extension system, which acts as a bridge between research and farming communities, is not robust. Only about half of the farm households in the country access technical advice and information, mostly from informal sources such as progressive farmers and input dealers. Outreach of the public extension is limited to a small proportion (<10%) of farm households. It is, therefore, imperative that investment in research be accompanied by more investment in extension.

Future growth in agriculture will be technology- and knowledge-intensive, and a lack of investment in R&D will slow down technical progress, which is essential for reducing poverty, combating malnutrition, and ensuring a healthy life. Hence, *investment in agricultural research made today will be crucial to shaping the future trajectory of agricultural growth and its economic, social, and environmental outcomes*.

1 Introduction

Over the past five decades, science, technology, and innovations in and for agriculture, supported by massive investments in irrigation, roads, electricity and markets, institutions (credit and extension), and incentives (input subsidies and output price support), have transformed India from a food-insecure to a food-surplus nation. Between 1970-71 and 2022-23, the production of foodgrains increased from 108 to 330 million tons and horticultural crops from 45 to 355 million tons. Progress in dairying, poultry, and fisheries has even been more significant. During this period, milk production increased from 22 to 230 million tons, fish from 1.75 to 16.25 million tons, and eggs from a meagre 0.13 to 2.77 million tons. The technology-led growth in agriculture enabled millions of smallholder producers and poor consumers to escape the vicious cycle of poverty and undernutrition, enhanced the country's resilience to cope with climatic and non-climatic shocks, reduced import dependence, and improved capacity to export.

The payoffs to investment in agricultural research have been estimated pretty attractive, ranging from Rs 7 to 11 for every rupee spent (Fan et al., 2000; Fan et al., 2008; Gulati and Terway, 2018). Alston et al. (2022) have estimated a benefit-cost ratio of 10:1 for CGIAR (Consultative Group on International Agricultural Research) research. Using an updated and larger dataset, Fuglie and Echeverria (2024) have reported an even higher payoff to investment. Note that India has been one of the main beneficiaries of the CGIAR research (Fuglie and Echeverria, 2024).

The social outcomes of technology- and innovation-led growth in agriculture have also been shown to be quite significant (Thirtle et al., 2003; Ravallion and Datt, 1995; Datt and Ravallion, 2002; Datt et al., 2016; Gulati and Terway, 2018; Fuglie et al., 2022). Studies have established that in developing countries, including India, agricultural growth is more pro-poor than growth in other economic sectors (Ravallion and Datt, 1995; Datt and Ravallion, 2002). Gulati and Terway (2018) estimate that in India, 328 people could escape poverty for every million rupees spent on agricultural research. Further, agricultural research for climate adaptation and mitigation has also been reported quite effective in improving agriculture's resilience to climate change (Birthal et al., 2015; Coger et al., 2021; Fuglie et al., 2022). The World Development Report 2008 highlights the crucial role of agricultural research in the transformation of the agri-food system as: "*improving the productivity, profitability, and sustainability of smallholder farming using agriculture for development is the main pathway out of poverty, with innovations through science and technology being one of the key instruments*" (World Bank, 2008).

Despite significant progress in food production in India, the need to produce more food, feed, fibre, and fuel remains as urgent as ever. By 2047 – the centenary year of India's independence – the population will cross the 1.6 billion mark, and about half of it will live in cities and towns. People will be more affluent and demand more diverse and nutrient-rich foods of both plant and animal origin. The demand for agricultural produce for feed, fuel, and fibre is also expected to be significantly higher. Overall demand for food is projected at least twice the current demand but with significant differences in its growth across food commodities (NITI Aayog, 2024).

However, agricultural production systems will confront several biotic and abiotic challenges. For the past three decades, India's net sown area has stagnated at around 140 million hectares, implying little scope for extensification of the existing agricultural land. Its intensification will come under severe pressure of growing water and energy scarcity (Garg and Hassan, 2007; Jain, 2011; Saleth, 2011). Besides, climate change has emerged as a significant threat to the sustainability of agriculture. India ranks seventh on the list of countries highly exposed to climate change (see Climate Change Performance Index of the GERMANWATCH: ccpi.org). During the past four decades, climate change could reduce India's agricultural growth by one-fourth (Birthal et al., 2021a). Given the predictions of intense changes in climate, its adverse effects on agricultural productivity, food security, nutrition, and poverty will be more severe in the future without adaptation and mitigation (Birthal et al., 2021b). Further, despite the remarkable progress in food production, approximately 11% Indians suffer from food and nutrition insecurity (FAO, 2022). Since agriculture is dominated by smallholders cultivating not more than one hectare of land, they will suffer the most from such challenges.

Notwithstanding, science, technology, innovations, and information have significant potential to address multiple challenges of enhancing agricultural productivity and farm incomes and their resilience to climate risks, mitigating emission of greenhouse gases, preserving natural resources, biodiversity, and environment, combating malnutrition and reducing poverty (Rosegrant et al., 2022). Agricultural research in India, however, has remained underinvested. From 2011 to 2020, India invested

0.61% of its AgGDP in agricultural research, which is about two-thirds of the global average of 0.93% and significantly less than 1-5% in several developed countries (Jayne et al., 2023). In 2020-21, India spent 0.54% of its AgGDP on research and 0.11% on extension.

During the early Green Revolution, India immensely benefitted from the knowledge and technology spill-overs of public-funded research in rich countries and the CGIAR (Fuglie and Echeverria, 2024). However, scientific research in and for agriculture is gradually moving into the private sector domain, accompanied by strong protection through intellectual property rights (IPR). Globally, in 2014, about one-fourth of the investment in agricultural research came from the private sector (Ruane and Ramasamy, 2023). According to Pardey et al. (2016), in 2011, over 52% of the research on crop breeding, informatics, fertilizers, pesticides, and food technologies in rich countries was carried out in the private sector, up from 42% in 1980. In middle-income countries, the share of private-sector investment in agricultural research more than doubled during this period, from 16% to 35%. Ruane and Ramasamy (2023) have also shown a faster increase in private investment in agricultural research in high- and middle-income countries. Thus, developing countries' access to technologies, innovations, and knowledge will be severely affected. The private-sector investment in agricultural research in developing countries is meagre (Ruane and Ramasamy, 2023). For instance, the private sector accounts for about 8% of the total agricultural research investment in India. Given the dominance of smallholders in agriculture, the need for more public spending on agricultural research cannot be discounted. Note that research involves high fixed costs and often a long gestation period to produce technologies and innovations — it takes several years to develop new crop varieties, fertilizers, pesticides, growth hormones, veterinary drugs and vaccines, animal breeds, machines, equipment, etc.

Further, harnessing the economic and social benefits of investment in research requires a robust extension system, which acts as a bridge between research and farming communities to deliver technologies, innovations, knowledge, and information. However, only about half of the farm households in India have access to technical advice and information, mostly from informal sources (GoI, 2021). Outreach of the public extension in India remains limited to less than 10% of the farm households. From 2010 to 2020, India spent 0.16% of its AgGDP on agricultural extension. However, with increasing biotic and abiotic pressures on agriculture and emerging consumer preferences for diverse, nutritious, and safe foods in international and domestic markets, farmers' demand for technical advice, information, and support services is expected to increase exponentially.

Therefore, it is imperative to invest in agricultural research to search for cost-effective, sustainable solutions to the current and future challenges to the transformation of agri-food systems aligning with the United Nation's sustainable development goals of reducing hunger, undernutrition, and poverty while preserving natural resources, biodiversity, and the environment. This paper assesses the economic rates of returns to investment in research and extension in Indian agriculture at the aggregate and sub-sector levels. Such information is of significant utility for decision-makers to justify public investment in agricultural R&D and its prioritization across disciplines, commodities, and sub-sectors to derive maximum economic, environmental, and social benefits.

The rest of the paper is organized as follows. Chapter 2 briefly describes the historical developments in India's agricultural research and extension policies. Chapter 3 discusses the size, sources, and trends in investment in agricultural R&D. Sub-sectoral allocations of public R&D investment are discussed in Chapter 4. Inter-state variations in R&D investment are highlighted in Chapter 5. Chapter 6 provides a framework for estimating payoff from investment in R&D, and Chapter 7 discusses the estimated payoffs from investment in R&D at the aggregate and sub-sector levels. The last Chapter provides the key findings and their implications for agricultural science policy.

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2 India's Agricultural R&D Policy

India's agricultural R&D policy has evolved in response to the acute food shortages (due to low and unsustainable crop yields and frequent climate risks) and significant dependence on food imports before the advent of the Green Revolution in the mid-1960s. Now, India has one of the largest public-funded National Agricultural Research, Education and Extension System (NAREES) to (i) conduct research on crops, animals, fisheries, farm mechanization, agro-forestry, conservation of natural resources, biodiversity, adaptation and mitigation to climate change, and the environment, (ii) develop domestic capacity for quality education in agriculture and allied sciences, and (iii) undertake on-farm testing of technologies and practices in different agro-climatic zones, and refining these, if necessary, before their wide-scale dissemination to farming communities and other stakeholders. Thus, agricultural research, education, and extension are inseparable and inextricably linked to agricultural growth and its economic, social, and environmental outcomes.

2.1 Agricultural science policy[1]

The history of India's agricultural science policy can be traced to the last quarter of the nineteenth century when the Colonial Government under the British Empire created a Department of Revenue, Agriculture and Commerce during the 1880s and engaged scientific manpower in it. Scientific research began with the establishment of the Imperial Bacteriological Laboratory (i.e., Indian Veterinary Research Institute) and five veterinary colleges in 1890. In 1905, the Imperial (Indian) Agricultural Research Institute and six colleges were established to conduct research and impart education in agriculture. Subsequently, the Imperial Institute of Animal Husbandry and Dairying (i.e., National Dairy Research Institute) was established in 1923.

However, the most significant milestone in the history of agricultural research was the establishment of the Imperial (Indian) Council of Agricultural Research (ICAR) in 1929 to fund and coordinate research in agriculture and allied sciences. Later, a few Central Commodity Committees

[1] For more details, see Pal and Byerlee (2006), Pal (2008), and Pal (2017).

were constituted for research on commercial crops such as cotton, lac, jute, sugarcane, coconut, tobacco, oilseeds, areca nut, cashew nut, and spices. Subsequently, the Composite Regional Stations were established for cotton, oilseeds, and millets. Both the Central Commodity Committees and Composite Regional Stations were later brought under the administrative control of the ICAR to improve coordination of research activities. A significant step towards strengthening the coordination in agricultural research was the initiation of the All India Coordinated Research Projects (AICRPs) on several food and non-food commodities in 1957.

ICAR was reorganized in 1965 and given greater functional autonomy and a renewed mandate of directing, coordinating, and advancing research in agricultural sciences. Further, to strengthen its linkages with state governments and international research organizations, the Government of India, in 1973, created the Department of Agricultural Research and Education (DARE) in the Ministry of Agriculture and designated the Director General of ICAR as its Secretary. Eight regional committees were constituted to provide solutions to location-specific agricultural problems through research and innovations.

A revolutionary change in agricultural science policy occurred in the late 1950s and early 1960s when the Government of India, inspired by the land-grant pattern of the USA[2], considered establishing agricultural universities in states. The first agricultural university (SAU) was established in 1960 at Pant Nagar, Uttar Pradesh (now in Uttarakhand). Further, on the recommendations of the Education Commission (1964-66) and the Review Committee on Agricultural Universities (1977-78), all matters related to research, education, and frontline extension in a state were transferred to the SAUs.

India has, now, a vibrant agricultural research and education system, with ICAR at the apex to coordinate, guide, and manage strategic and applied research and education. There are 113 research institutions under ICAR (four deemed universities, 65 national institutes, six national bureaus, 13 project directorates, 15 national research centres, and 11 ATARIs — Agricultural Technology Application Research Centres). Most of these conduct basic and applied research on commodities/activities as mandated to them but are of national importance. In addition, there are three Central Agricultural Universities (CAUs), 64 SAUs and 60 AICRPs.

[2] The land-grant model emphasizes the integration of research, education, and extension.

2.2 Agricultural extension policy[3]

To harness the potential of science and innovations for the social and economic upliftment of rural communities, the Government of India in 1952 started the Community Development Project, one of the earliest attempts to evolve an organized support system for agriculture and rural development. Soon after, in 1953, the National Extension Service Program was launched to promote the application of scientific innovations in upstream agriculture. In 1958, Directorate of Extension was established in the Ministry of Agriculture to support states in training infrastructure for efficient delivery of agricultural technologies and services.

Further, the Intensive Agricultural District Program (IADP) in 1961 and the Intensive Agricultural Areas Program (IAAP) in 1964 were launched to push the adoption of improved agricultural technologies and agronomic practices in the regions with significant potential for the production of staple foodgrains, i.e., rice and wheat. In 1964, ICAR also started the National Demonstrations Project to validate the technologies developed in its research institutes and those acquired from other countries and international research organizations in farmers' fields before recommending their large-scale transfer to farming communities. It launched the Operational Research Project in 1974 and the Lab-to-Land Program in 1979 to take technologies and innovations to farming communities.

However, a significant change in extension policy transpired with the establishment of the Krishi Vigyan Kendras (KVKs) or Farm Science Centres, and the Trainers Training Centres (TTCs) in 1974 to (i) empower extension personnel in assessing the suitability of technologies and practices under different agro-climatic zones, their refinement, and on-farm demonstrations; and (ii) to build farmers' capacity to improve uptake of recommended technologies and practices, and to seek their feedback on their performance and limiting factors. Currently, there are 731 KVKs spread throughout the country (in almost all districts). Their activities are coordinated and monitored by the ATARIs.

The introduction of the Training and Visit (T&V) system in 1974 was another sea-change in the agricultural extension system. It emphasized a single-line command to fix extension personnel's administrative and technical responsibilities for coordinating and implementing agricultural development programs and strengthening linkages between extension and research to ensure the timely delivery of technologies and services. The

3 For details, see Babu and Joshi (2019).

National Agricultural Extension Project (NAEP) launched in 1979 further emphasized research-extension-farmer linkages.

The National Demonstrations Project, the Operational Research Project, and the Lab-to-Land Program were merged with the KVK system in 1992. In 1999, the ICAR established the first 'Agricultural Technology Information Centres (ATIC)' to serve as a "single window" for delivering advisory services, information, seeds, and plant material to farming communities.

After a long hiatus, recognizing the crucial role of extension in agricultural development, in 2005 the Government of India implemented a centrally-sponsored scheme 'ATMA - Agricultural Technology Management Agency' to (i) support states in the delivery of technologies and good agricultural practices, and (ii) empower farmers through training, demonstrations, exposure visits, farm fairs, farmer-groups, and farm schools for the adoption of sustainable agricultural practices.

Over the past three decades, India has witnessed significant growth in digital innovations (mobiles, internet, etc.). These have considerable potential to transform agricultural extension and service delivery systems from a physical to a digital interface between service providers and farmers, reducing the costs of acquisition of technical advice and information, and delivery time. The Government of India has also established voice-based Kisan Call Centres and a digital platform, Kisan Sarathi, to disseminate the right kind of information in the proper form and at the right time.

India's agricultural extension system is now quite diverse. It includes several public and private entities. Public extension comprises the state departments of agriculture, research institutes, SAUs, and KVKs; and private extension includes the progressive farmers, input dealers, electronic media (television, radio, mobile, internet, etc.), non-governmental organizations, farmer producer organizations, agri-business firms, etc. To encourage private extension, the Government of India has also implemented a scheme, 'Agri-Clinics and Agri-Business Centres (AC & ABC),' for unemployed agricultural graduates to engage them to deliver context- and location-specific information. Still, about half of the farm households need access to agricultural information and technical services (GoI, 2021). Outreach of the public extension remains limited to less than 10% of the farm households.

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3 Size and Sources of Investment in Agricultural R&D

3.1 Trend in R&D investment

Table 3.1 presents the decade-wise average annual investment in agricultural R&D (at 2011-12 prices)[1] for the past four decades. Investment in R&D has increased 4.8 times, from Rs 31,096 during 1981-1990 to Rs 1,48,653 million per annum during 2011-2020. Throughout, the research has accounted for the bulk (around 80%) of the investment, and extension accounted for the rest.

There was a noticeable jump in investment during the 1990s and 2010s. This could have been because of the agricultural sector being under pressure to adjust to the economic reforms that began in 1991 and also to manage the negative externalities of intensive agriculture to natural resources and climate change. Further, in 1995, India signed the Agreement on Agriculture of the World Trade Organization, which required member countries not to allow market-distorting incentives (e.g., subsidies and price incentives) beyond the prescribed limits.

Table 3.1. Average investment in agricultural R&D, 1981-2020

Period	(Rs million/annum) at 2011-12 prices)			% share in total R&D investment	
	Research	Extension	Total	Research	Extension
1981-1990	23830	7266	31096	76.63	23.37
1991-2000	44020	10769	54789	80.34	19.66
2001-2010	71000	14236	85236	83.30	16.70
2011-2020	118510	30143	148653	79.72	20.28

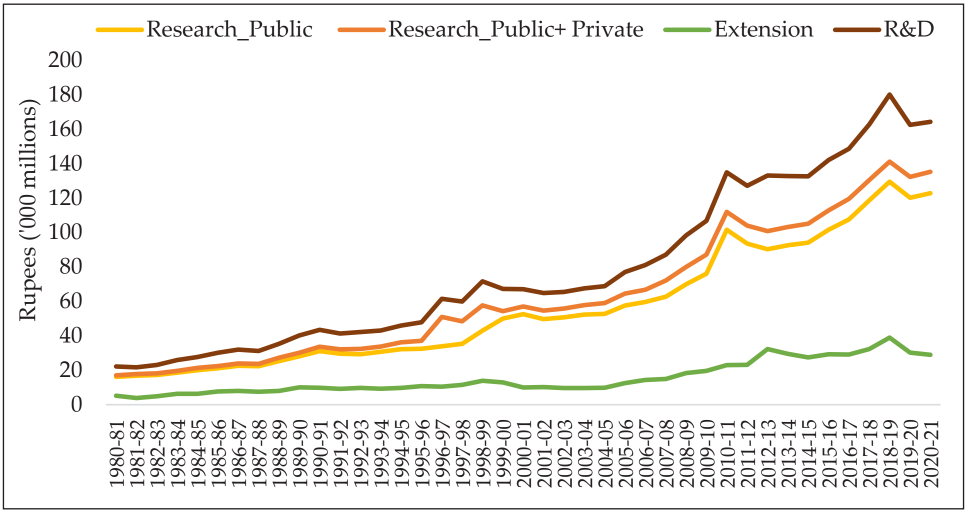
Note: Investment in research includes investment in education and private-sector investment.
Source: Public investment (GoI, various years, a), and private investment (GoI, various years, b).

[1] R&D includes research, education, and extension, and is adjusted for inflation using the GDP deflator.

It may be noted that the technological gains of the Green Revolution started decelerating after the mid-1990s, and the deceleration was aggravated by climate change. The country faced four severe droughts in the past two decades — in 1999-2000, 2002-03, 2012-13, and 2015-16, and also the global food crisis in 2007-08. All these events necessitated more investment in agricultural research, targeting the enhancement of agricultural productivity and its resilience to climate change, and arresting deterioration of natural resources. The economic reforms also paved the way for private sector participation in agricultural research.

The decadal averages mask year-on-year fluctuations. Figure 3.1 shows the trend in annual investment in agricultural R&D. A significant increase is observed between 2004-05 and 2011-12, which, however, after a slight decline in the early 2010s, started rising again and reached an all-time high of Rs 1,80,181 million in 2018-19. However, in the subsequent years, it has declined. Interestingly, the behaviour of public-sector and private-sector investment in research is almost similar,[2] indicating that private investment has a little crowding-out effect on public spending on agricultural research. Instead, given the vast size of India's NAREES in terms of infrastructure and human resources, there are ample opportunities for public-private partnerships and collaborations.

Figure 3.1. Trend in annual investment in R&D



Source: As for Table 3.1.

2 Correlation coefficient between public-sector and private-sector investment in research is estimated 0.74.

3.2 Sources of R&D investment

Most research, education, and extension activities are undertaken in public-sector institutions funded by the central and state governments through their annual budgets. Over the past four decades, public-sector investment comprised 87-95% of the total R&D investment (Table 3.2). Agriculture is a state subject. Hence, states account for a sizable share in the total investment in R&D. During 1981-1990, central and state governments accounted for 34% and 62% of the total investment, respectively. Nevertheless, a gradual shift has happened in the funding pattern. The states' share declined to 49% from 2001-2010, and that of the central government increased to 42%. During 2011-2020, their respective shares stood at 58% and 34%. The share of private investment increased from about 5% during 1981-1990 to 13% during 1991-2000 but fell to 8% during 2011-2020.

Further, we look at the changes in the funding sources separately for research and extension. From 1981 to 1990, states accounted for over half of the total investment in research, which, after declining to 43% during 2001-2010, recovered to its previous level. The share of the central government dropped from 43% during 1981-1990 to 39% during 1991-2000. It, however, increased to 46% during 2001-2010 but fell to 40% during 2011-2020. On the other hand, the share of the private sector, after peaking at 15% in the 1990s,

Table 3.2. Average investment in R&D by source, 1981-2020

Activity	Period	(Rs million/annum) at 2011-12 prices			% share		
		Centre	States	Private	Centre	States	Private
Research	1981-1990	10060	12290	1480	42.6	51.3	6.1
	1991-2000	17320	19610	7090	39.3	45.6	15.2
	2001-2010	32850	30480	7670	45.9	43.4	10.7
	2011-2020	47536	59584	11390	40.1	50.3	9.6
Extension	1981-1990	436	6830	NA	6.0	94.0	NA
	1991-2000	711	10058	NA	6.6	93.4	NA
	2001-2010	2851	11385	NA	20.0	80.0	NA
	2011-2020	2718	27426	NA	9.0	91.0	NA
Total	1981-1990	10496	19120	1480	33.8	61.5	4.8
	1991-2000	18031	29668	7090	32.9	54.1	12.9
	2001-2010	35701	41865	7670	41.9	49.1	9.0
	2011-2020	50254	87010	11390	33.8	58.5	7.7

Note: NA stands for not available.
Source: As for Table 3.1.

plummeted to 10% during 2011-2020. A substantial hike in private-sector investment during the 1990s can be attributed to the economic reforms.

Requirements for extension services are location- and context-specific. Hence, the bulk of the investment (about 90%) in agricultural extension comes from states. The central government provides funds for the testing and refining of technologies/agronomic practices and their frontline demonstrations. A higher share of the central government in extension investment during 2001-2010 was primarily due to the implementation of the ATMA and expansion of the KVK system.

Table 3.3 presents the patterns in the growth in R&D investment over the past four decades. The growth in research investment decelerated, falling to 4.4% during 2011-2020 from 6.4% per annum from 1980 to 1990. However, there is a contrast in the investment behaviour of the central and state governments. The growth in the central government investment slowed down, while it accelerated in the case of states. The growth in private investment decelerated at a faster rate. The growth patterns in public and private investment provide credence to our observation of the minor, if any, crowding-out effect of private investment on public investment in agricultural research.

The growth in extension investment has been cyclical, with ridges and troughs. It decelerated significantly to 1.6% during the 1990s from 7.7% during the 1980s, accelerated again to 7.6% during 2001-2010, and fell to 4.5% during 2011-2020.

Table 3.3. Percent annual growth in R&D investment (at 2011-12 prices)

	Research					
	Public					
Period	Centre	State	Total	Private	Total	Extension
1981-1990	4.72	6.61	5.74	13.01	6.41	7.70
1991-2000	6.73	4.09	5.34	9.79	5.91	1.55
2001-2010	5.92	5.90	5.93	4.40	5.55	7.57
2011-2020	2.90	6.24	4.63	2.41	4.42	4.49

Source: As for Table 3.1.

Given the challenges of climate change and quantitative and qualitative degradation of natural resources, the deceleration in investment will slow down technical progress, essential for ensuring food security, reducing poverty, and combating malnutrition. Our findings suggest the need for (i) arresting the deceleration in growth in public-sector investment in research and extension and (ii) creating an enabling environment for private and philanthropic investment in agricultural research.

3.3 Intensity of R&D investment

Although investment in R&D has increased considerably, it is imperative to probe it in relation to AgGDP and cropped area, i.e., investment intensity, which is a more relevant indicator for policy decisions regarding the adequacy of research resources and their future requirements. Table 3.4 presents the proportion of AgGDP spent on agricultural research and extension. The intensity of R&D investment (including investment in extension and private-sector investment in research) increased from 0.53% during 1981-1990 to 0.76% during 2001-2010, and after that, it remained almost stagnant. Expectedly, the intensity of public-sector investment has been slightly lower — 0.50% during 1981-1990 and 0.71% during 2011-2020.

Table 3.4. Percent of AgGDP spent on R&D, 1981-2020

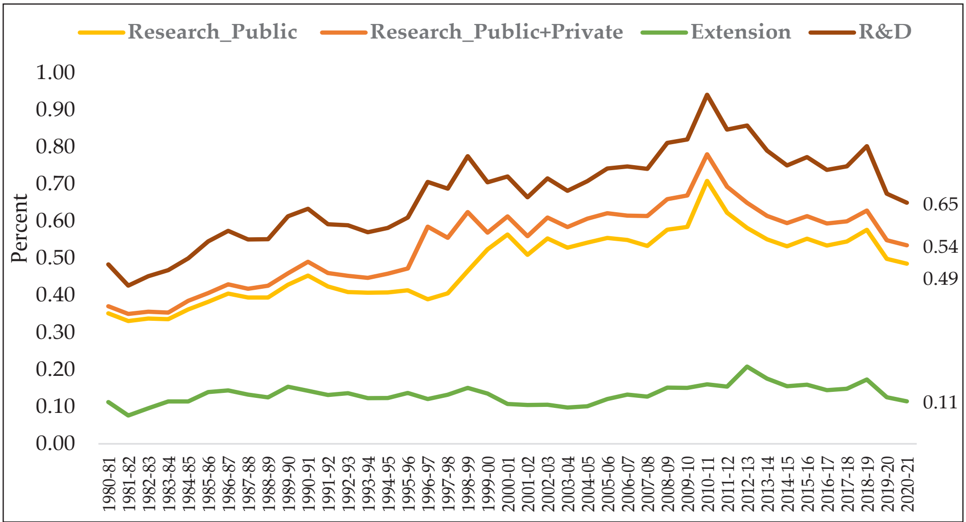
Period	Research			Extension	Total R&D
	Public	Private	Total		
1981-1990	0.38	0.03	0.41	0.12	0.53
1991-2000	0.44	0.08	0.52	0.13	0.65
2001-2010	0.56	0.07	0.63	0.13	0.76
2011-2020	0.55	0.06	0.61	0.16	0.77

Source: As for Table 3.1.

If one considers investment in research (public plus private) alone, its intensity is estimated to have increased from 0.41% during 1981-1990 to 0.61% from 2011 to 2020. The intensity of public-sector investment has risen from 0.38% during 1981-1990 to 0.44% during 1991-2000 and further to 0.55-0.56% in the following two decades. On the other hand, the intensity of extension investment, after remaining stagnant at 0.12-0.13% for three decades, increased to 0.16% during 2011-2020.

Figure 3.2 shows the trend in the intensity of annual investment in R&D. It has behaved in a cyclical manner, first rising and then falling (or remaining stagnant) every 5-7 years (Figure 3.2). For example, it increased until 1991, declined over the next five years, increased again, and so on. Nevertheless, it peaked at 0.94% in 2010-11 but declined to 0.65% in 2020-21. This pattern also mirrors in the public-sector investment. In 2020-21, the intensity of public-sector investment in research and extension was estimated at 0.49% and 0.11%, respectively. The intensity of R&D investment, therefore, is characterized by significant annual fluctuations.[3] It may be noted that India's research intensity has yet to reach the level of 0.77% that high-income countries had in the early 1960s (Ruane and Ramasamy, 2023).

Figure 3.2. Trend in AgGDP spent on R&D



Source: As for Table 3.1.

The intensity of R&D investment, measured per unit of gross cropped area, increased from Rs 174/ha during 1981-1990 to Rs 751/ha during 2011-2020 (Table 3.5). As expected, the intensity of research investment is higher than that of extension. During this period, public investment in research increased from Rs 125/ha to Rs 541/ha and private investment from Rs 8/ha to Rs 58/ha. Notably, there is a significant correlation between the two measures of R&D investment intensity.

Table 3.5. Average investment in R&D at 2011-12 prices (Rs/ha of gross cropped area/annum)

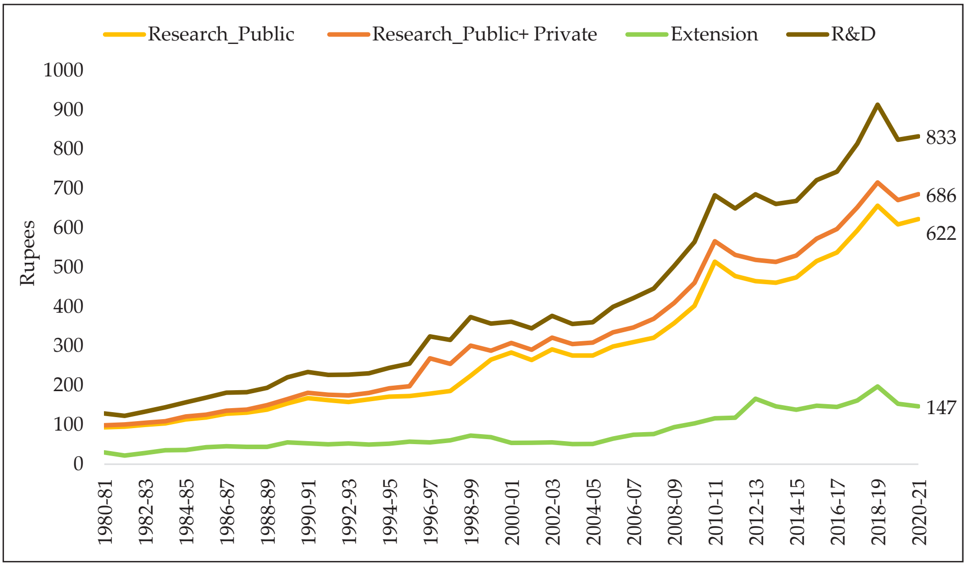
Period	Research			Extension	Total R&D
	Public	Private	Total		
1981-1990	125	8	133	41	174
1991-2000	197	38	234	57	292
2001-2010	331	40	371	74	446
2011-2020	541	58	599	152	751

Source: As for Table 3.1.

[3] Coefficient of variation is estimated 18.71% in research investment, and 18.44% in extension investment.

Figure 3.3 shows the trend in annual investment in R&D per hectare of gross cropped area. Investment in research increased from Rs 101/ha in 1980-81 to Rs 686/ha in 2020-21, and in extension from Rs 30/ha to Rs 147/ha.

Figure 3.3. Trend in annual investment in R&D per ha of gross cropped area at 2011-12 prices



Source: As for Table 3.1.

This analysis provides two key messages. First, compared to the research intensity at the global level, India's research intensity is comparatively low. Looking towards the fast-growing demand for food and non-food commodities amidst the increasing challenges of climate change and the degradation of natural resources, biodiversity, and the environment, investment in research needs to be increased continuously to match the global level by 2030. Second, agricultural research involves significant fixed costs and a long gestation period. Since there is no crowding-out effect of private investment on public investment, there is a need to strengthen public-private partnerships to unlock the full potential of fixed investment and manpower available in the public sector.

♦♦♦

4 Sub-sectoral Composition of R&D Investment

The agricultural sector has four broad sub-sectors: crops, livestock, fisheries, and forestry. However, studies on research and extension investments and returns from these at the disaggregate levels are lacking. A sound understanding of these is essential to prioritizing research and development agendas, considering their economic, social, and environmental contributions. This chapter provides a synoptic view of the allocation of R&D resources across sub-sectors of agriculture.

Throughout the past four decades, crops have shared the bulk (82-85%) of the R&D investment (Table 4.1). The share of livestock declined from 12.2% during 1981-1990 to 9.2% during 2011-2020, and the share of fisheries and natural resources[1] increased but erratically. However, there is a contrast in the trend in the funding of research by the central and state governments. Over time, central government investment in R&D on crops has gradually declined while the states have increasingly focused on crops.

Table 4.1. Percent share of sub-sectors in public investment in R&D, 1981-2020

Source	Period	Crops	Livestock	Fisheries	Natural resources
Centre	1981-1990	95.1	3.7	0.7	0.5
	1991-2000	86.2	7.9	4.6	1.3
	2001-2010	76.5	9.7	5.4	8.5
	2011-2020	79.9	8.5	4.2	7.4
States	1981-1990	78.2	16.7	2.9	2.1
	1991-2000	82.2	13.4	2.6	1.8
	2001-2010	86.1	10.6	1.8	1.5
	2011-2020	88.6	9.6	1.6	0.1
Total	1981-1990	84.1	12.2	2.1	1.6
	1991-2000	83.7	11.4	3.3	1.6
	2001-2010	81.5	10.2	3.5	4.8
	2011-2020	85.1	9.2	2.6	3.0

Source: As for Table 3.1.

[1] Investment in soil and water conservation is termed as the investment in natural resources.

A similar pattern unfolds for research and extension investments (Table 4.2 and 4.3). Crop sciences shared 80% or more of the total investment in research, while animal sciences lost their share to 10.2% during 2011-2020 from 13.9% during 1981-1990. During this period, the fisheries gained, and the natural resources lost. Again, there is a contrast in the funding pattern of the central and state investments. Over time, central government has started emphasizing animal husbandry, fisheries, and natural resources, while states have focussed on crops, leading to a drastic decline in the share of other components of agriculture. For example, animal sciences lost their share from 21.9% during 1981-1990 to 11.3% during 2011-2020.

Table 4.2. Percent share of sub-sectors in research investment, 1981-2020

Source	Period	Crops	Livestock	Fisheries	Natural resources
Centre	1981-1990	95.5	3.9	0.2	0.3
	1991-2000	86.8	8.2	4.0	0.9
	2001-2010	74.9	10.5	5.4	9.1
	2011-2020	78.9	9.0	4.3	7.8
States	1981-1990	73.4	21.9	2.8	1.9
	1991-2000	77.9	18.2	2.6	1.3
	2001-2010	85.2	11.7	1.6	1.5
	2011-2020	86.9	11.3	1.7	0.1
Total	1981-1990	83.3	13.9	1.7	1.2
	1991-2000	82.0	13.6	3.3	1.1
	2001-2010	79.6	11.1	3.7	5.7
	2011-2020	82.9	10.2	3.0	4.0

Source: As for Table 3.1.

As in the case of research, crops have remained the focus of agricultural extension. For example, from 2011 to 2020, crops shared 92% of the total investment in agricultural extension. Livestock accounted for a meagre, 6.2%, and most of it came from states. The share of fisheries and natural resources has declined drastically.

Table 4.3. Percent share of sub-sectors in extension investment, 1981-2020

Source	Period	Crops	Livestock	Fisheries	Natural resources
Centre	1981-1990	85.0	0.1	10.1	4.8
	1991-2000	71.0	0.2	18.1	10.8
	2001-2010	92.9	0.3	5.4	1.43
	2011-2020	97.8	0.1	2.1	0.1
States	1981-1990	86.9	7.4	3.2	2.5
	1991-2000	90.8	3.9	2.5	2.7
	2001-2010	88.1	8.1	2.4	1.4
	2011-2020	91.5	6.8	1.5	0.3
Total	1981-1990	86.8	6.9	3.6	2.6
	1991-2000	89.5	3.7	3.6	3.2
	2001-2010	89.1	6.5	3.0	1.4
	2011-2020	92.1	6.2	1.5	0.2

Source: As for Table 3.1.

Table 4.4 shows the distribution of the sectoral total R&D investment between research and extension. In the case of crops, research has accounted for three-fourths of the total R&D investment throughout the past four decades. The share of research is even higher (>85%) in the case of livestock. Interestingly, this pattern has remained almost unchanged over time. On the other hand, research has consolidated its share in R&D investment for fisheries and natural resources.

Table 4.4. Percent share of research and extension in sub-sector R&D investment, 1981-2020

Source	Sub-sector	Activity	1981-1990	1991-2000	2001-2010	2011-2020
Centre	Crops	Research	96.3	96.7	89.7	93.5
		Extension	3.7	3.3	10.3	6.5
	Livestock	Research	99.9	99.9	99.7	99.95
		Extension	0.1	0.1	0.3	0.05
	Fisheries	Research	35.7	84.3	91.6	97.4
		Extension	64.3	15.7	8.4	2.6
	Natural resources	Research	61.5	67.0	98.6	99.9
		Extension	38.5	33.0	1.4	0.1

Contd.

Table 4.4 contd.

Source	Sub-sector	Activity	1981-1990	1991-2000	2001-2010	2011-2020
States	Crops	Research	60.1	63.3	69.5	61.2
		Extension	39.9	36.7	30.5	38.8
	Livestock	Research	84.1	90.2	77.3	73.6
		Extension	15.9	9.8	22.7	26.4
	Fisheries	Research	61.0	67.6	61.3	65.3
		Extension	39.0	32.4	38.7	34.7
	Natural resources	Research	58.2	49.2	71.6	36.7
		Extension	41.8	50.8	28.4	63.3
Total	Crops	Research	74.4	76.1	78.6	73.3
		Extension	25.6	23.9	21.4	26.7
	Livestock	Research	85.8	92.7	87.5	83.4
		Extension	14.2	7.3	12.5	16.6
	Fisheries	Research	58.3	76.1	83.4	85.7
		Extension	41.7	23.9	16.6	14.3
	Natural resources	Research	58.6	54.6	94.3	98.1
		Extension	41.4	45.4	5.7	1.9

Source: As for Table 3.1.

Finally, we look into the pattern of growth in R&D investment in sub-sector (Table 4.5). From the 1990s onwards, investment in R&D for crops increased at an accelerated rate, primarily due to an acceleration in extension investment. On the other hand, growth in investment for livestock has decelerated significantly from 4.6% during the 1980s to 2.4% from 2011 to 2020 despite an acceleration in extension investment. Also, there has been a significant deceleration in growth in investment for fisheries and natural resources.

There emerge two key messages from this analysis. First, the continued underinvestment in R&D for livestock, fisheries, and natural resources, and deceleration in its growth are serious concerns on several counts. Livestock contributes about 30% to AgGDP and its contribution has grown faster than the crop sub-sector. The fisheries sub-sector, too, has grown faster. From 2011 to 2020, both the sub-sectors experienced an all-time high growth of around 8% per annum. Their social contributions are even more appealing. Evidence indicates that these activities act as a buffer during extreme climate shocks and significantly contribute to poverty reduction (Birthal and Negi, 2012; Bijla et al., 2023). Likewise, the increasing negative externalities of intensive agriculture to natural resources and the growing threat of climate change reinforce the need for more allocation of resources for research on the conservation of natural resources and climate adaptation and mitigation. Looking towards the current and future challenges to agriculture, there is an urgent need to revisit the R&D portfolio.

Table 4.5. Percent annual growth in R&D investment in sub-sectors

Investment	Crops	Livestock	Fisheries	Natural resources
Research				
1981-1990	5.49	4.78	7.06	5.65
1991-2000	4.91	4.19	9.60	11.32
2001-2010	4.70	3.12	4.93	10.74
2011-2020	4.81	1.69	0.59	0.84
Extension				
1981-1990	5.07	3.27	3.77	5.35
1991-2000	4.18	2.88	3.30	0.52
2001-2010	5.77	7.44	1.13	-7.73
2011-2020	6.21	7.16	-0.01	-7.92
Total				
1981-1990	5.20	4.64	5.95	5.91
1991-2000	4.74	4.05	7.88	9.62
2001-2010	4.96	3.61	4.10	7.64
2011-2020	5.13	2.39	0.50	-0.80

Source: As for Table 3.1.

Second, agricultural R&D has remained heavily biased toward research. However, the gains from research may remain subdued without a robust extension system for the delivery of research outputs. Agriculture will be technology- and knowledge-intensive in the future. Hence, farmers' requirements for technical advice and information on various aspects of agri-food system from upstream to downstream will increase exponentially. Given an extremely low outreach of the public extension system, investment in agricultural research must be accompanied by more investment in public extension.

5 Regional Disparities in Investment in Agricultural R&D

India is of continental size and characterized by significant spatial variations in climate, infrastructure, markets, and institutions, which, by influencing the product and technology portfolios, can potentially lead to regional imbalances in agricultural growth and its economic, social and environmental outcomes. Nevertheless, science, technology, and innovations have considerable potential to bridge gaps in regional development (Birthal et al., 2011; Hazrana et al., 2019).

Table A5.1 (in the appendix) presents the decade-wise average investment in agricultural R&D of states. R&D investment has increased in all states but differentially over different decades (Table 5.1). During the 1980s — the heydays of the Green Revolution — it increased significantly in most states. However, there was an equally strong deceleration in it during the 1990s but an acceleration afterward. Patterns in growth in R&D investment, however, differ significantly across states. The growth in R&D investment continued to accelerate in Andhra Pradesh, Kerala, Arunachal Pradesh, Meghalaya, Nagaland, Goa, Madhya Pradesh, Rajasthan and Uttar Pradesh. In Haryana and West Bengal, it decelerated significantly from 2011 to 2020. In Punjab, Himachal Pradesh, Tamil Nadu, and Karnataka, after a continuous deceleration during the 1980s and 1990s, it witnessed an acceleration from 2011 to 2020. On the other hand, it has continued to decelerate in Maharashtra and Gujarat.

Table 5.1. Percent annual growth in investment in agricultural R&D in states

State	1981-1990	1991-2000	2001-2010	2011-2020
Andhra Pradesh	6.00	7.00	12.29	11.31
Arunachal Pradesh	11.78	3.85	8.81	13.20
Assam	12.82	4.61	9.46	2.68
Bihar	6.93	-3.10	7.68	0.97
Chhattisgarh	-	-	2.69	5.03
Goa	11.74	3.12	5.72	8.61
Gujarat	9.33	5.05	5.74	2.70
Haryana	4.06	8.47	9.35	2.52

Contd.

Table 5.1 contd.

State	1981-1990	1991-2000	2001-2010	2011-2020
Himachal Pradesh	16.78	6.29	1.76	7.80
Jammu & Kashmir	18.35	6.26	1.60	7.07
Jharkhand	-	-	0.16	4.90
Karnataka	6.06	4.91	3.35	4.22
Kerala	4.98	4.11	5.29	10.44
Madhya Pradesh	10.41	1.37	3.08	7.68
Maharashtra	8.85	5.03	5.51	1.29
Manipur	16.66	-1.72	-3.20	-4.95
Meghalaya	9.29	1.37	3.18	7.87
Mizoram	2.18	1.69	13.92	2.77
Nagaland	-0.41	-0.48	6.04	6.33
Odisha	11.27	0.78	-5.81	31.50
Punjab	8.40	4.27	1.07	6.74
Rajasthan	6.31	-2.84	1.50	6.99
Sikkim	3.55	1.66	-3.84	12.86
Tamil Nadu	9.13	7.51	4.13	6.63
Tripura	-3.14	-0.32	21.50	-10.55
Uttar Pradesh	12.15	2.13	8.45	9.94
Uttarakhand	-	-	1.69	6.77
West Bengal	3.07	5.38	10.41	-4.32

Source: As for Table 3.1.

Table 5.2 presents the intensity of R&D investment (as a proportion of AgGDP and per unit of cropped area). The proportion of AgGDP spent on agricultural R&D increased in most states, except Gujarat, Madhya Pradesh, Maharashtra, and Nagaland, where it remained almost constant. On the other hand, it declined in Uttar Pradesh, Rajasthan, Odisha, Manipur, and Sikkim. Tables A5.2 and A5.3 (in the appendix) respectively provide the intensity of research and extension.

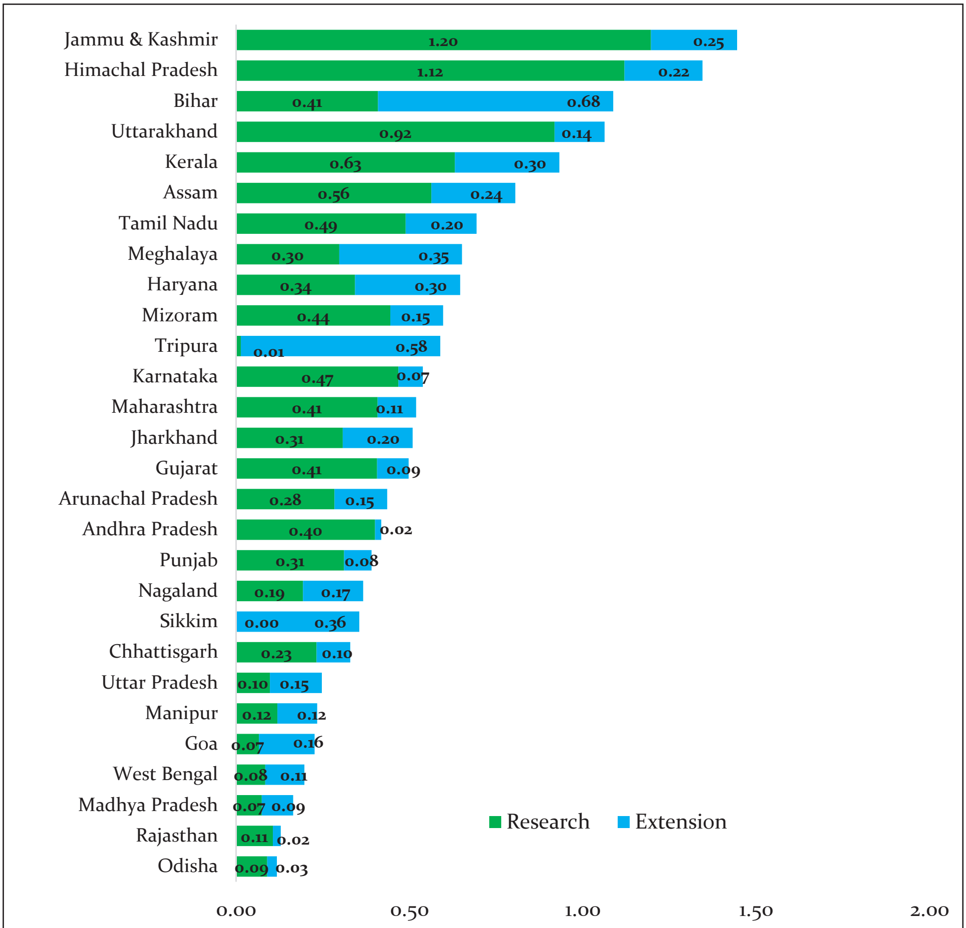
Table 5.2. Decade-wise intensity of R&D investment in states

State	% of AgGDP				Rs/ha of GCA/annum			
	1981-1990	1991-2000	2001-2010	2011-2020	1981-1990	1991-2000	2001-2010	2011-2020
Andhra Pradesh	0.29	0.37	0.37	0.42	74	147	226	644
Arunachal Pradesh	0.51	0.67	0.36	0.44	234	387	270	889
Assam	0.58	0.49	0.73	0.81	242	271	476	739
Bihar	0.59	0.57	0.46	1.09	153	189	264	1086
Chhattisgarh	-	-	0.22	0.33	-	-	78	211
Goa	0.17	0.17	0.24	0.23	136	156	222	442
Gujarat	0.44	0.53	0.49	0.50	143	205	253	518
Haryana	0.35	0.36	0.61	0.65	138	211	460	755
Himachal Pradesh	0.81	1.05	1.02	1.35	371	702	1148	1941
Jammu & Kashmir	0.75	0.81	1.35	1.45	421	610	1229	1992
Jharkhand	-	-	0.49	0.51	-	-	606	863
Karnataka	0.17	0.22	0.36	0.54	66	126	192	443
Kerala	0.41	0.46	0.38	0.93	251	472	525	1948
Madhya Pradesh	0.12	0.17	0.18	0.16	23	38	60	121
Maharashtra	0.51	0.51	0.50	0.52	153	217	250	372
Manipur	0.46	0.45	0.27	0.23	442	477	269	205
Meghalaya	0.53	0.53	0.50	0.65	320	417	506	786
Mizoram	0.39	0.26	0.34	0.60	303	300	431	1090
Nagaland	1.03	0.37	0.42	0.37	403	239	357	375
Odisha	0.16	0.19	0.13	0.12	53	62	55	166
Punjab	0.03	0.06	0.29	0.39	147	180	233	444
Rajasthan	0.35	0.24	0.20	0.13	63	56	57	79
Sikkim	1.14	1.02	0.65	0.36	228	290	267	376
Tamil Nadu	0.55	0.81	0.83	0.69	239	540	742	1452
Tripura	0.16	0.11	0.40	0.59	106	98	362	873
Uttar Pradesh	0.21	0.32	0.24	0.25	66	129	109	192
Uttarakhand	-	-	1.03	1.06	-	-	809	1440
West Bengal	0.30	0.17	0.18	0.20	146	121	179	293

Source: As for Table 3.1.

Figures 5.1 and 5.2 present the intensity of R&D from 2011 to 2020. The Himalayan states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand, Kerala, Assam, and Bihar spent comparatively more on R&D — 0.80% to 1.45% of their AgGDP (Figure 5.1). Tamil Nadu, Haryana, Meghalaya, Mizoram, Tripura, Karnataka, Maharashtra, Jharkhand, and Gujarat spent 0.50% to 0.69%. On the other hand, Odisha, Rajasthan, Madhya Pradesh, West Bengal, Goa, Manipur, and Uttar Pradesh spent between 0.12% to 0.25% of their AgGDP.

Figure 5.1. Percent of AgGDP spent on R&D in states, 2011-2020



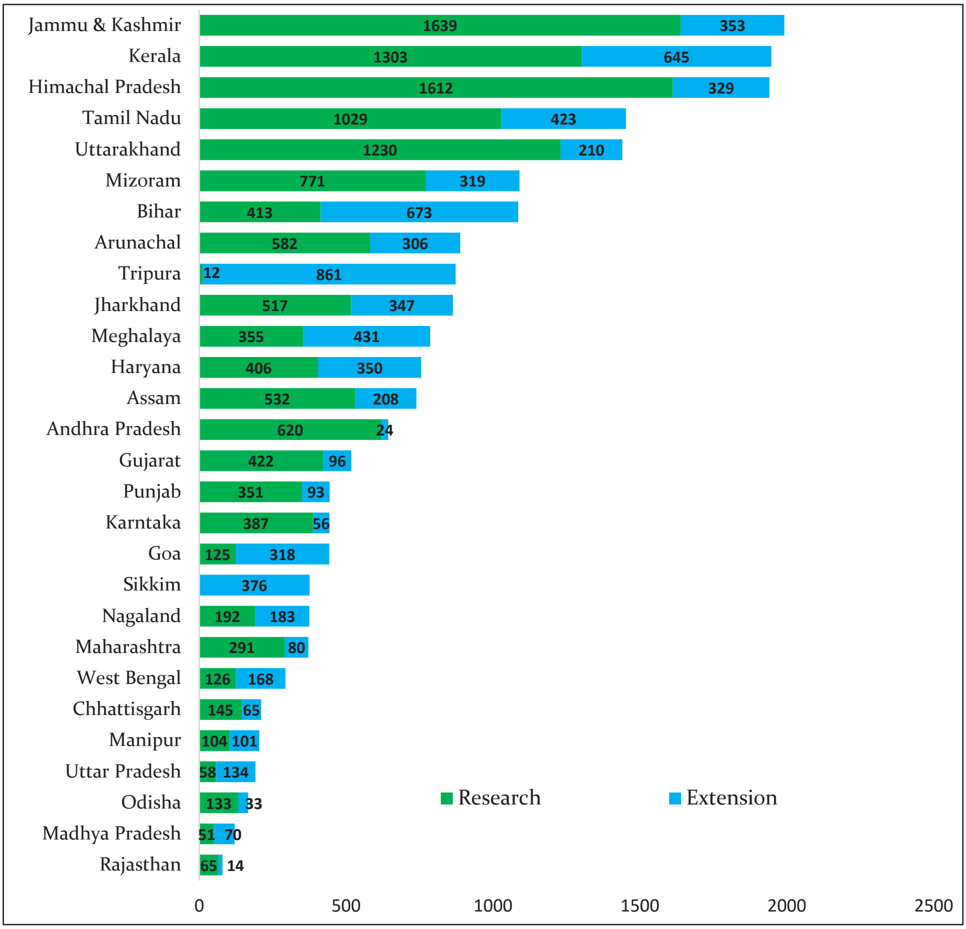
Source: As for Table 3.1.

Regarding spending per hectare of gross cropped area, states' ranking remains almost unchanged (Figure 5.2).

Figures 5.1 and 5.2 also show the intensity of research and extension. Bihar, Meghalaya, Sikkim, Tripura, Jharkhand, Uttar Pradesh, West Bengal, and

Madhya Pradesh have spent more on extension than research. In contrast, Odisha, Gujarat, Rajasthan, Punjab, Andhra Pradesh, Karnataka, and Uttarakhand have spent little on it. These findings indicate a significant imbalance in resource allocation between research and extension.

Figure 5.2. Investment in R&D, 2011-2020 (Rs/ha of gross cropped area/ annum)



Source: As for Table 3.1

Table 5.3 shows the shares of sub-sectors in the total R&D investment during 2011- 2020. Haryana, Uttar Pradesh, Gujarat, Rajasthan, Bihar, Odisha, West Bengal, and Assam spent over 90% of the total on crops. In Punjab, Himachal Pradesh, Jammu & Kashmir, Chhattisgarh, Madhya Pradesh, Maharashtra, Manipur, and Nagaland, the share of crops ranged between 80% and 90%. Livestock shared more than 20% of the total R&D investment in Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Uttarakhand, Arunachal Pradesh, and Sikkim. Except in southern states, the research portfolio has remained heavily biased towards crops. Likewise, the extension investment has excessively concentrated on crops. The distribution of research and extension investment at the sub-sector level is provided in Table A5.4 (in the appendix).

Table 5.3. Percent share of sub-sectors in agricultural R&D in states, 2011-2020

State	Crops	Livestock	Fisheries	Natural resources
Andhra Pradesh	71.05	23.42	2.81	2.72
Arunachal Pradesh	67.07	29.93	0.93	2.06
Assam	93.91	1.76	3.66	0.67
Bihar	93.50	2.93	0.16	3.41
Chhattisgarh	84.02	13.59	2.37	0.01
Goa	76.42	17.54	5.34	0.70
Gujarat	94.50	4.65	0.83	0.02
Haryana	99.20	0.12	0.54	0.14
Himachal Pradesh	88.92	10.09	0.91	0.08
Jammu & Kashmir	87.02	11.63	0.58	0.77
Jharkhand	98.76	1.23	0.01	0.00
Karnataka	66.94	27.54	4.84	0.69
Kerala	71.83	22.21	5.75	0.21
Madhya Pradesh	80.12	15.09	0.35	4.45
Maharashtra	86.61	10.04	1.23	2.12
Manipur	86.38	2.64	6.50	4.48
Meghalaya	75.77	2.31	2.26	19.66
Mizoram	63.89	14.93	0.82	20.36
Nagaland	83.15	5.84	6.62	4.40
Odisha	92.34	2.08	4.80	0.79
Punjab	83.35	14.99	0.12	1.54
Rajasthan	91.44	6.98	0.29	1.29
Sikkim	79.45	20.35	0.14	0.05
Tamil Nadu	70.42	24.27	4.73	0.58
Tripura	68.60	16.36	13.66	1.38
Uttar Pradesh	93.30	6.21	0.31	0.18
Uttarakhand	74.66	24.50	0.26	0.58
West Bengal	93.67	2.83	2.93	0.57

Note: In some states (i.e., Haryana and Jharkhand), there seems to be a discrepancy in data reporting for different sub-sectors.

Source: As for Table 3.1.

These findings suggest the need for a consistent increase in the funding of agricultural research and extension in Rajasthan, Odisha, Madhya Pradesh, Uttar Pradesh, and West Bengal and balancing the R&D portfolio across sub-sectors of agriculture, and between research and extension in each sub-sector. Some states, for example, Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Assam, Kerala, and Bihar, need to enhance research efficiency by improving the factors that facilitate the dissemination and adoption of technologies, innovations, knowledge, and information.

♦♦♦

6 Methodology for Estimating Payoffs to Investment in Agricultural R&D

6.1 Data sources and variables

A panel dataset on 18 major Indian states for a period of 31 years, from 1990 to 2020, has been used to estimate the payoff from investment in agricultural R&D and other activities. These states are Andhra Pradesh (including Telangana), Assam, Bihar (including Jharkhand), Goa, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh (including Chhattisgarh), Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttarakhand), and West Bengal.[1]

As discussed earlier, both the state and central governments fund agricultural research. However, most studies have considered only states' investments in estimating the payoff. The central government does provide funds for agricultural R&D, but to the ICAR primarily for research. The ICAR has a pan-India presence through its research institutes. Hence, not accounting for the central government's investment may bias the estimates.

The ICAR has a national mandate for research and education, but apportioning its budget to states is complex. In apportioning their funds to states, we have assumed that the benefits of research conducted in an institute in a state do not remain confined to the state itself but spillover to other states. The budgets of crop science institutes have been distributed to states in proportion to their shares in the total cropped area. Similarly, the budgets of animal science research institutes have been distributed in proportion to states' shares in the total livestock population.[2] Some institutes undertake research on location-specific commodities/problems. Their budgets have been apportioned to states based on the spatial concentration of the commodity or the problem. The rest of the ICAR's budget has been apportioned to states in proportion to their shares in the total cropped area.

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1 States indicated in brackets were carved out of the states mentioned before brackets at different points of time. Hence, to maintain a spatial and temporal consistency in data series, these were merged with their parent states.

2 Population of different livestock species has been standardized into cattle-equivalent units (CEU). Population of buffaloes, camels, equines was multiplied by 1.25, of pigs by 0.25, of sheep and goats by 0.13, and of poultry birds by 0.001.

Payoffs to investment in research and extension have been estimated at the aggregate and sub-sector (i.e., crops and livestock) levels. Table 6.1 provides sources of data, their definitions, and measurement units.

Table 6.1. Data sources and definition of variables used in modeling impact of R&D

a. Agricultural sector

Variable	Definition	Date source	Unit of measurement	Unit used in analysis
AgGDP	Agricultural Gross Domestic Product	National Account Statistics, Ministry of Statistics and Programme Implementation, Government of India (NAS)	Rs million	Rs/ha
LAB	Labour force in agriculture	Census of India, Ministry of Home Affairs, GoI	Number	No. /ha
FERT	Fertiliser consumption	Agricultural Statistics at a Glance, Ministry of Agriculture & Farmers Welfare, GoI	Tons	Kg/ha
GCA	Gross cropped area		’000 ha	-
CANAL	Share of Canal irrigated area		’000 ha	%
GW	Share of Well irrigated area		’000 ha	%
ELEC	Electricity consumption in agriculture		‘000 Gwh	‘000Kwh/ha
RLIT	Rural literacy rate	NSSO reports on social consumption expenditure (education) in India, Ministry of Statistics and Programme Implementation, GoI	%	%
RAIN	Rainfall	Indian Meteorology Department, Ministry of Earth Sciences, GoI	mm	mm
ROAD	Road density	Basic Road Statistics, Ministry of Road Transport and Highways, GoI	km	Km/sq.km
FERTS	Fertilizer subsidy	Fertilizer Statistics of India, Department of Fertilizers, GoI	Rs million	Rs/ha

Contd.

Table 6.1 contd.

Variable	Definition	Date source	Unit of measurement	Unit used in analysis
POPD	Population density	Census of India	Number	No. / sq.km.
RD	Public expenditure on R&D	Combined Finance and Revenue Account, Comptroller & Auditor General of India, GoI	Rs million	Rs/ha
EXT	Public expenditure on extension			
INCANAL	Public expenditure on medium and major projects			
LNWELL	Public expenditure on minor irrigation			
INELEC	Public expenditure on electric power for agriculture			
LITEXP	Public expenditure on education			Rs/capita
EROAD	Public expenditure on roads			Rs/sq.km.

b. Crop sub-sector

Variable	Definition	Date source	Unit of measurement	Unit used in analysis
VOPC	Value of output of crops	NAS	Rs million	Rs/ha
LAB	Labour force in agriculture	Census of India, Ministry of Home Affairs, GoI	Number	No. /ha
MECH	Tractors	Livestock Census, Ministry of Fisheries, Animal Husbandry and Dairying, GoI	Number	Numbers/ No. /ha
FERT	Fertiliser consumption	Agricultural Statistics at a Glance, Ministry of Agriculture & Farmers Welfare, GoI	Tons	Kg/ha
GCA	Gross cropped area		'000 ha	-
CANAL	Share of Canal irrigated area		'000 ha	%
GW	Share of Well irrigated area		'000 ha	%
ELEC	Electricity consumption in agriculture		'000 Gwh	'000Kwh/ ha
RLIT	Rural literacy rate	NSSO reports on social consumption expenditure (education) in India, Ministry of Statistics and Programme Implementation, GoI	%	%

Variable	Definition	Date source	Unit of measurement	Unit used in analysis
RAIN	Rainfall	India Meteorology Department, Ministry of Earth Sciences, GoI	mm	mm
ROAD	Road density	Basic Road Statistics, Ministry of Road Transport and Highways, GoI	km	Km/ sq.km
FERTS	Fertilizer subsidy	Fertilizer Statistics of India, Department of Fertilizers, GoI	Rs million	Rs/ha
POPD	Population density	Census of India	Number	No./ sq.km.
HVC	Area under high-value crops (fruits, vegetables, condiments and spices and commercial crops)	Agricultural Statistics at a Glance	%	%
CRD	Public expenditure on R&D in crop sub-sector	Combined Finance and Revenue Account, Comptroller & Auditor General of India, GOI	Rs million	Rs/ha
CEXT	Public expenditure on extension in crop sub-sector			
INCANAL	Public expenditure on medium and major projects			
LNWELL	Public expenditure on minor irrigation			
INELEC	Public expenditure on electric power for agriculture			
LITEXP	Public expenditure on education			
EROAD	Public expenditure on roads			
INCROP	Expenditure on crop husbandry development and soil water conservation			
EHD	Public expenditure on horticultural & commercial crops development			

c. Livestock sub-sector

Variable	Definition	Date source	Unit of measurement	Unit used in analysis
LOP	Livestock population	Livestock Census	Numbers	Cattle-equivalent * (million)
VOPL	Value of output of livestock	NAS	Rs million	Rs/CEU
AI	Number of artificial inseminations	Basic Animal Husbandry Statistics, Ministry of Fisheries, Animal Husbandry and Dairying, GoI	Numbers	No./ CEU
VETS	Number of veterinarians per livestock unit		Numbers	No./CEU
MCOP	Milk procured by dairy cooperatives	Annual Reports, National Dairy Development Board (NDDB)	Million ton	Ton/milch animal
COOP	Number of village dairy cooperatives		No.	No./CEU
RLIT	Rural literacy rate	NSSO reports on social consumption expenditure (education) in India, Ministry of Statistics and Programme Implementation, GoI	%	%
ROAD	Road density	Basic Road Statistics, Ministry of Road Transport and Highways, GoI	km	Km/sq.km
POPD	Population density	Census of India	Number	No. /sq.km.
LRD	Public expenditure on livestock R&D	Combined Finance and Revenue Account, Comptroller & Auditor General of India, GOI	Rs million	Rs/CEU
ELES	Public expenditure on livestock extension			
EVHS	Public expenditure on livestock health and veterinary services			
EDD	Public expenditure on dairy development			
ELDP	Public expenditure on livestock development			
LITEXP	Public expenditure on education			Rs/capita
EROAD	Public expenditure on roads			Rs/sq.km.

6.2 Econometric model for estimating payoff to investment in R&D

To quantify the payoff to investment in agricultural R&D, the widely used structural equation model capable of capturing linkages of technologies, inputs, infrastructure, investments, and agricultural growth, is employed (Hazell et al. 2000; Fan et al. 2008b; Bathla et al. 2019; Gulati and Terway, 2018). All variables defined in Table 6.1 have been converted into their natural logarithms.

Payoffs to investment in research and extension are estimated at the aggregate and sub-sector levels.[3] Hausman's test was performed to determine the suitability of different estimating approaches to the dataset. Test results presented in Table 6.2 suggest the superiority of the 3-stage least square (3SLS) over the seemingly unrelated regression (SUR) for the agricultural sector and its livestock component, and of the SUR over the 3SLS for the crop sub-sector.

Table 6.2. Model specification test results

Dataset	Null hypothesis	Chi-square	p-value	Decision
Agricultural sector	SUR is preferred over 3SLS	241.29	0.000	H0 is rejected
Crop sub-sector	SUR is preferred over 3SLS	13.08	1.000	Ho is accepted
Livestock sub-sector	SUR is preferred over 3SLS	54.43	0.000	H0 is rejected

6.2.1 Structural model for agricultural sector

Equations included in the structural model for the agricultural sector are:

$$AgGDP_{st} = f\,(LAB_{st},\ FERT_{st},\ RAIN_{st},\ RLIT_{st}, RD_{st}, T) \quad \dots (1)$$

$$FERT_{st} = f\,(CANAL_{st}, GW_{st},\ FERTS_{st},\ EXT_{st}, T) \quad \dots (2)$$

$$CANAL_{st} = f\,(RAIN_{st},\ INCANAL_{st}, T) \quad \dots (3)$$

$$GW_{st} = f\,(RAIN_{st}, INWELL_{st}, ELEC_{st}, T) \quad \dots (4)$$

$$RLIT_{st} = f\,(ROAD_{st}, LITEXP_{st}, T) \quad \dots (5)$$

$$ROAD_{st} = f\,(POPD_{st},\ EROAD_{st}, T) \quad \dots (6)$$

$$ELEC_{st} = f\,(INELEC_{st}, T) \quad \dots (7)$$

Where s represents the state, t is the year, and T is the time trend.

[3] Investment in the conservation of natural resources has been combined with investment in crops.

6.2.2 Structural model for crop sub-sector

The following equations comprise the structural model for the crop sub-sector.

$$VOPC_{st} = f\,(LAB_{st}, MECH_{st}, FERT_{st}, HVC_{st}, RLIT_{st}, RAIN_{st}, CRD_{st}, INCROP_{st}, T) \qquad ...(8)$$

$$FERT_{st} = f\,(CANAL_{st}, GW_{st}, CEXT_{st}, FERTS_{st}, ROAD_{st}, T) \qquad ...(9)$$

$$HVC_{st} = f\,(RAIN_{st}, CANAL_{st}, GW_{st}, ROAD_{st}, EHD_{st}, T) \qquad ...(10)$$

$$CANAL_{st} = f\,(RAIN_{st}, INCANAL_{st}, T) \qquad ...(11)$$

$$GW_{st} = f\,(RAIN_{st},, INWELL_{st}, ELEC_{st}, T) \qquad ...(12)$$

$$RLIT_{st} = f\,(ROAD_{st}, LITEXP_{st}, T) \qquad ...(13)$$

$$ROAD_{st} = f\,(POPD_{st}, EROAD_{st}, T) \qquad ...(14)$$

$$ELEC_{st} = f\,(INELEC_{st}, T) \qquad ...(15)$$

6.2.3 Structural model for livestock sub-sector

The following equations are included in the structural model for the livestock sub-sector.

$$VOPL_{st} = f\,(AI_{st}, VETS_{st},, MCOP_{st}, LRD_{st}, EVHS_{st}, ELES_{st}, ELDP_{st}, T) \qquad ...(16)$$

$$MCOP_{st} = f\,(COOP_{st}, EDD_{st}, RLIT_{st}, T) \qquad ...(17)$$

$$RLIT_{st} = f\,(ROAD_{st}, LITEXP_{st}, T) \qquad ...(18)$$

$$ROAD_{st} = f\,(POPD_{st}, EROAD_{st}, T) \qquad ...(19)$$

6.2.4 Payoff to investment in R&D

Using the regression coefficients (β_s) of the relevant variables from the structural equations, the payoffs to investment in R&D and other activities have been estimated as follows.

$$Agricultural\ research = \left(\frac{dAgGDP}{dRD}\right) = \beta_{RD} * \left(\frac{\overline{AgGDP}}{\overline{RD}}\right) \qquad ...(20)$$

$$Agricultural\ extension = \left(\frac{dAgGDP}{dFERT}\right) * \left(\frac{dFERT}{dEXT}\right) = \beta_{FERT} * \left(\frac{\overline{AgGDP}}{\overline{FERT}}\right) * \beta_{EXT} * \left(\frac{\overline{FERT}}{\overline{EXT}}\right) \qquad ...(21)$$

$$Crop\ research = \left(\frac{dVOPC}{dCRD}\right) = \beta_{CRD} * \left(\frac{\overline{VOPC}}{\overline{CRD}}\right) \qquad ...(22)$$

$$Crop\ extesion = \left(\frac{dVOPC}{dFERT}\right) * \left(\frac{dFERT}{dCEXT}\right) = \beta_{FERT} * \left(\frac{\overline{VOPC}}{\overline{FERT}}\right) * \beta_{CEXT} * \left(\frac{\overline{FERT}}{\overline{CEXT}}\right) \qquad ...(23)$$

$$Livestock\ research = \left(\frac{dVOPL}{dLRD}\right) = \beta_{LRD} * \left(\frac{\overline{VOPL}}{\overline{LRD}}\right) \qquad ...(24)$$

$$Livestock\ extension = \left(\frac{dVOPL}{dELES}\right) = \beta_{ELES} * \left(\frac{\overline{VOPL}}{\overline{ELES}}\right) \qquad ...(25)$$

6.3 Research and development lags

Research involves high fixed costs and a long gestation period to generate technologies, innovations, knowledge, and information. Thus, current agricultural productivity is determined by the current and past investments. Research investment, therefore, builds a long-term stock of knowledge, the impact of which persists for several years. One way to account for this in estimating payoff is to construct a series of research stocks applying the perpetual inventory method (PIM) to the annual series of investments, assuming that the current year's investment in research generates a stock of knowledge without any gestation and depreciates immediately. However, a fundamental limitation here is that it is based on a single parameter, i.e., depreciation rate (Alston 2008; Alston et al., 2022), while research takes significant time to generate technologies and innovations after the initial investment and to realize their impacts. It is, therefore, imperative to include a suitable time lag in modeling payoff to investment.

There are several approaches to determining the lag length (e.g., polynomial distributed, inverted-V shaped, and lag-free). Polynomial distributed lag is the most widely used. It takes the shape of a bell in determining lag weights — the gestation period between initial investment and technology generation, the period of appreciating impact of technology, and the period of depreciating impact, which eventually becomes zero.

The most recent developments in designing a lag structure for polynomial distributed models include the trapezoid, geometric, or gamma distribution (Alston et al., 2010). The gamma distribution is often used to generate lag weights for investment in agricultural R&D (Alston et al., 2010). Assuming that investment equals stock once the technology is fully utilized, the lag weight in year 't' is bt, and ∑bt= 1.

$$bt = (t-g-1)^{\left(\frac{\phi}{1-\phi}\right)}\theta^{(t-g)} / \sum_{t=1}^{L}(t-g-1)^{\left(\frac{\phi}{1-\phi}\right)}\theta^{(t-g)} \qquad \ldots(26)$$

Where g is the gestation lag, 'ϕ' and 'θ' respectively represent the shape and scale parameters of the gamma distribution, and t=1, . . ., L (maximum lag length).

Studies estimating payoff to investment in agricultural R&D have used different lag lengths. From an extensive literature review, Alston et al. (2023) observed a lag length between 11 and 25 years as the most common. For developing countries, the lag length is reported relatively small (Alston et al., 2023; Rada and Schimmelpfennig, 2018; Joshi et al., 2015; Fan et al., 2000; Fan et al., 2008; Evenson et al., 1999).

We assume a three-year gestation period for research to generate a technology after the initial investment. Then, using weights from the gamma distribution, an optimal lag length has been identified based on the coefficient of determination (R^2) and Akaike Information Criterion (AIC). Optimal lag length corresponds to the highest value of R^2 and the lowest value of AIC. Accordingly, we have found a time lag of eight years for crop science research, 15 years for animal science research, and 12 years for aggregate agricultural research.

Once a technology or innovation is generated, it is validated through on-farm testing for its suitability to different environments. If necessary, it is refined before being recommended for large-scale dissemination. Hence, technology takes time to reach the farming communities. Farmers are exposed to new technologies and innovations through frontline demonstrations and capacity-building and training programs, and the effects of such extension activities persist for several years. Based on the above-defined criteria, a lag length of eight years has been identified for overall agricultural extension and crop extension. For livestock extension, it is estimated to be five years.

Besides, the effects of investment in other sector-specific and developmental activities such as roads, electric power, literacy, and irrigation persist for several years. Such investments have been converted into capital stocks by applying the PIM.

$$K_t = I_t + (1 - \delta) * K_t - 1 \qquad \ldots(27)$$

Where K_t and I_t respectively represent the capital stock and the investment in year t, and δ is the depreciation rate.[4]

[4] Depreciation rate of 10% is applied.

7 Payoffs to Investment in Agricultural R&D

7.1 Payoff to investment in R&D in agricultural sector

7.1.1 Estimates of structural model

Table 7.1 presents estimates of the structural model for the agricultural sector. Irrigation, electricity, road density, and extension are collinear. Therefore, these variables have not been included in Eq. (1). Nevertheless, based on their relevance, one or more of these have been included in other estimating equations.

Investment in research has a significant positive effect on agricultural productivity (Eq.1). Agricultural productivity is also positively and significantly associated with fertilizer use and rural literacy.

Spending on extension and fertilizer subsidies positively and significantly influences fertilizer use (Eq.2). It is also significantly associated with irrigation. Interestingly, fertilizer subsidy has a more significant effect on fertilizer consumption, indicating that fertilizer use is more responsive to the price (subsidized) that farmers pay.

Public-sector investment in medium and large irrigation schemes significantly and positively impacts expansion of the area under canal irrigation (Eq.3). However, it is negatively associated with rainfall. Expectedly, electricity supply has a significant positive impact on the expansion of the groundwater-irrigated area (Eq.4). However, unlike canal irrigation, it is not much impacted by public-sector investment in minor irrigation schemes.

Rural literacy is significantly and positively influenced by public-sector investment in education and road density (Eq. 5). Similarly, road density is positively and significantly affected by public-sector investment in road infrastructure and population density (Eq.6). Likewise, electricity use in agriculture is positively associated with investment in electricity generation and distribution (Eq.7).

Table 7.1. Estimates of structural equations for agricultural sector

Eq. No.	Dependent variables	Explanatory variables					R^2
1	AgGDP	+0.180FERT (6.26)*	+0.021LAB (0.77)	+0.038RAIN (1.04)	+0.084RD (4.50)*	+3.009RLIT (17.42)*	0.45
2	FERT	+0.071EXT (8.05)*	+0.029CANAL (1.62)**	+0.1251GW (13.01)*	+0.614FERTS (29.40)*		0.87
3	CANAL	-0.305RAIN (-4.42)*	+0.363INCANAL (8.93)*				0.26
4	GW	+0.05RAIN (0.44)	-0.320INWELL (-0.59)	+0.566ELECT (10.94)*			0.38
5	RLIT	+0.076ROAD (12.64)*	+0.125LITEXP (18.73)*				0.69
6	ROAD	+0.870POPD (30.56)*	+0.297EROAD (12.02)*				0.70
7	ELEC	+0.588INELECT (27.11)*					0.60

*Note: Figures in parentheses indicate z-values. * and ** respectively indicate significance at 5% and 10%.*

7.1.2 Payoffs to investment in agricultural R&D

Table 7.2 presents the payoffs from investment in research, extension, and other developmental activities. Investment in agricultural R&D is quite productive — every rupee invested in agricultural research pays off Rs 13.85. The payoff from investment in agricultural extension is almost half of it, i.e., Rs 7.40. On the other hand, the payoffs from investment in other developmental activities are not as significant. These results, by and large, align with those reported by Gulati and Terway (2018).

Table 7.2. Estimates of payoff to investment in agricultural R&D

Activity	Returns per rupee spent
Agricultural research	13.85
Agricultural extension	7.40
Canal irrigation	0.25
Roads	1.33
Education	2.05
Electric power	0.84

7.2 Payoff to investment in R&D in crop sub-sector

7.2.1 Estimates of structural model

Table 7.3 presents the results of the structural model for crops. Irrigation, roads, and electricity are collinear. Investment in crop extension is also highly correlated with research investment. Hence, these variables have not been included in the main equation (Eq.8).

Crop productivity, defined as the value of the output of crops per hectare of gross cropped area, is positively and significantly impacted by investment in crop science research (Eq.8). It is also significantly and positively associated with fertilizer use, rainfall, area under high-value food and commercial crops, and investment in crop husbandry development programs. Literacy also has a positive and significant impact on productivity. Diversification into high-value and commercial crops is an important source of growth (Birthal et al., 2014), and its effect on productivity is as expected.

Fertilizer use is significantly and positively impacted by the canal as well as groundwater irrigation, road density, and spending on extension and fertilizer subsidy (Eq.9). Importantly, crop diversification is positively and significantly impacted by groundwater availability, rainfall, road density (market access), and investment in programs for promoting it (Eq.10).

Table 7.3. Estimates of structural equations for the crop sub-sector

Eq. No.	Dependent variable	Explanatory variables								R^2
8	VOPC	+0.304FERT (15.02)*	-0.003LAB (-0.02)	+0.01MECH (1.16)	+0.100RAIN (3.92)*	+0.078CRD (9.65)*	+0.026HVC (1.93)*	+0.136INCROP (8.98)*	+0.877RLIT (11.19)*	0.77
9	FERT	+0.058CEXT (7.86)*	+0.082CANAL (7.13)*	+0.079GW (9.84)*	+0.067ROAD (5.28)*	+0.599FERTS (32.08)*				0.88
10	HVC	+0.231RAIN (2.79)*	-0.045CANAL (-1.19)	+0.099GW (3.49)*	+0.336ROAD (6.42)*	+0.176EHD (4.53)*				0.20
11	CANAL	-0.145RAIN (-1.5)	+0.471INCANAL (11.43)*							0.27
12	GW	-0.113RAIN (-0.9)	-0.277INWELL (-5.06)*	+0.378ELEC (8.80)*						0.37
13	RLIT	+0.086ROAD (13.31)*	+0.103LITEXP (10.22)*							0.64
14	ROAD	+0.645POPD (18.02)*	+0.249EROAD (10.46)*							0.70
15	ELEC	+0.572INELEC (27.75)*								0.63

*Note: Figures in parentheses indicate z-values. * and ** respectively indicate significance at 5% and 10%.*

As expected, public-sector investment in major and medium irrigation schemes has a significant positive impact on the expansion of canal irrigation (Eq. (11). Groundwater-irrigated area is positively associated with electric power supply to agriculture (Eq. 12). Investment in education and road infrastructure helps improve rural literacy (Eq. 13). Road density is positively influenced by public-sector investment in roads (Eq.14) and electricity use in agriculture by investment in electricity generation and distribution (Eq.15).

7.2.2 Payoffs to investment in R&D for crops

Table 7.4 presents the estimated payoff to investment in R&D in the crop sub-sector. For every rupee spent on crop science research, there is a payoff of Rs 11.69, and on crop extension, Rs 10.80. Further, the payoff to investment in crop husbandry development programs is also quite attractive (Rs 8.18). However, the payoffs to investment in other development activities are lower.

Table 7.4. Estimates of payoff to investment in R&D in crop sector

Activity	Returns per rupee spent
Crop research	11.69
Crop extension	10.80
Development of crop husbandry	8.18
Development of horticulture and commercial crops	0.64
Canal irrigation	1.04
Roads	1.06
Education	1.66
Electric power	0.46

7.3 Payoff to investment in R&D in livestock sub-sector

7.3.1 Estimates of structural model

Table 7.5 presents the results of the structural model for livestock. Investment in research, extension, health and veterinary services, and other livestock development programs significantly and positively impact livestock's performance (Eq.16). Adoption of crossbreeding technology (e.g., artificial insemination) and access to milk markets (i.e., cooperatives) also have a positive and significant impact.

Dairy cooperatives have been leading the way, linking farmers to markets. As expected, the expansion of village dairy cooperatives significantly influences milk sales or farmers' access to the milk market (Eq. 17). Rural literacy also has a significant positive impact on milk sales. As observed earlier also, literacy is significantly and positively influenced by investment in education and road density (Eq.18); and road density by expenditure on road infrastructure (eq.19).

Table 7.5. Estimates of structural equations for livestock sub-sector

Eq. No.	Dependent variable	Explanatory variables							R^2
6	VOPL	+0.151AI (6.06)*	+0.027VETS (0.53)	+0.173MCOP (11.19)*	+0.060LRD (4.49)*	+0.026EVHS (1.83)**	+0.130ELDP (3.9)*	+0.03ELES (1.76)**	0.73
17	MCOP	+1.366COOP (41.8)*	+0.027EDD (1.47)	+0.916RLIT (3.12)*					0.87
18	RLIT	+0.075ROAD (10.77)*	+0.145LITEXP (16.06)*						0.67
19	ROAD	+0.436POPD (12.47)*	+0.532EROAD (17.6)*						0.75

*Note: Figures in parentheses indicate z-values. * and ** respectively indicate significance at 5% and 10%.*

7.3.2 Payoffs to investment in R&D for livestock

Table 7.6 presents the payoffs to investment in livestock research, extension, and other developmental activities. Investment in animal science research is hugely productive — every rupee spent pays off Rs 20.81, nearly double the payoff from crop science research. The payoff to investment in livestock extension is also quite attractive, Rs 6.17.

The payoffs to investment in other programs (i.e., animal husbandry development and health and veterinary services) are also encouraging. Unexpectedly, the payoff to investment at the mid-stream of the value chain (processing and value addition) is insignificant, probably due to the spatial concentration of milk procurement. For example, Gujarat accounts for about 9% of the total milk production but makes significant contribution (about 45%) to the total milk procured by the cooperatives. Nonetheless, the payoff from investment in dairy infrastructure will improve with the investment in dairy development in lagging states.

Table 7.6. Estimates of payoff to investment in R&D in livestock sub-sector

Activity	Returns per rupee spent
Livestock Research	20.81
Livestock Extension	6.17
Animal husbandry development	9.75
Animal health and veterinary services	3.38
Dairy development	0.18
Roads	0.04
Literacy	0.09

4.4 Discussion

In this sub-section, we discuss two critical issues: How does India's agricultural research investment compare with other countries? How do our estimates of payoffs to public-sector investment in agricultural research and extension compare with those reported in other studies?

We begin by comparing intensity of public-sector investment in agricultural research (Table 7.7). In 2016, globally 0.93% of the AgGDP was spent on agricultural research (Jayne et al., 2023), but there were significant inter-regional differences. Most countries in sub-Saharan Africa (excluding South Africa) and Asia (except China and India) spent less than 0.4% of their AgGDP. China spent 0.64% of its AgGDP on agricultural R&D (Jayne et al., 2023), and India spent 0.53% (this study). Ruane and Ramasamy (2023) have estimated that high-income countries, on average, spent 3.12% of their AgGDP on agricultural research from 2009 to 2013, more than four times the level of 0.77% during 1960-1964. Notably, India has not reached the level that high-income countries had during the early 1960s.

Public-sector investment in agricultural research in developed and middle-income countries has continued to grow but slowly (Ruane and Ramasamy, 2023), probably due to the increasing private investment in agricultural research. According to Pardey et al. (2016), in 2011, in rich countries, over 52% of the research on crop breeding, informatics, fertilizers, pesticides, and food technologies was carried out in the private sector, up from 42% in 1980. In middle-income countries, the share of private-sector investment in agricultural research has also more than doubled, from 16% to 35%. In developing countries, including India, private-sector investment in agricultural research is little. In India, during 2011- 2020, private investment comprised 8% of the total investment in agricultural research. The low level of private investment is because the private sector is attuned to market opportunities and charges higher prices for its products. While, the resource-poor farmers in developing countries cannot afford to pay high prices. Nevertheless, there is a need to identify potential areas for research in the public and private sectors based on their relative strengths and weaknesses.

Table 7.7. Intensity of public investment in agricultural research in different regions of the world, 2016

Developing/ developed regions	Region	% of AgGDP spent on R&D
Developing regions	Central America	0.75
	South America	1.40
	China	0.64
	Southeast Asia	0.35
	India	0.53
	South Asia	0.28
	West & Central Asia	0.70
	North Africa	0.40
	Sub-Saharan Africa	0.30
Developed regions	Central Europe	0.97
	Western Europe	3.03
	Canada-USA	2.27
	Australia-NZ-S Africa	1.94
	Japan-Korea-Taiwan	4.61
	World	0.93

Source: Jayne et al. (2023). Figures for sub-Saharan Africa exclude South Africa. The figure for India is from our study.

Further, we compare our estimated payoffs to investment in agricultural research and extension with those reported in other studies. Globally, several studies have assessed the payoffs to investment in agricultural research. From an extensive literature review, Alston et al. (2009) have reported a median internal rate of returns (IRR) of 42%. Likewise, Pardey et al. (2018) have reported a median IRR of 37% and a benefit-cost ratio of 12:1. Alston et al. (2022), from a meta-analysis of the impact of CGIAR crop technologies have estimated a benefit-cost ratio of 10:1. Fuglie and Echeverria (2024) have reported an even higher rate of returns to investment in CGIAR research.

In India, the payoffs to investment in agricultural research have also been quite attractive (Fan et al., 2000; Fan et al., 2008; Rada and Schimmelpfennig, 2018; Gulati and Terway, 2018). Gulati and Terway (2018) have estimated every rupee spent on agricultural research yielding a payoff of Rs 11.20 (Table 7.8). On the other hand, Bathla et al. (2019) estimate a much smaller payoff, i.e., Rs 2.47 at the national level, but higher in low-income states.

Bathla et al. (2019) and Gulati and Terway (2018) used data from the same sources for the same period. Yet, they arrived at different payoffs, probably because of the differences in estimating procedures and the construction of dependent and independent variables. Our estimated payoff of Rs 13.85 is bigger than those reported in other studies.

Table 7.8. Previous estimates of payoff to investment in R&D

Author(s)	Study period	Payoff (Rs) for one-rupee spent	
Fan et al. (2000)	1970-1993	Overall	: 6.01
Fan et al. (2008)	1967-1997	1967-79	: 8.65
		1980-89	: 7.93
		1990-97	: 9.50
Gulati and Terway (2018)	1980-2014	Overall	:11.20
Bathla et al. (2019)	1981-2013	High-income states	: 3.23
		Middle-income states	: 4.44
		Low-income states	: 9.92
		Overall	: 2.47

Leaving aside the estimates by Bathla et al. (2019), an over-time comparison of the payoffs indicates an improvement in the efficiency of agricultural research. From a synthesis of the empirical evidence from several developing countries, Mogues et al. (2012) have also reported an improvement in the payoffs. There could be several reasons for this, but important ones are: (i) reduction in gestation lag due to significant advances in basic and applied research in and for agriculture, and (ii) improvements in logistics and communication networks essential for quick dissemination of technologies, innovations, services, and information to the end-users.

Our study differs from other studies in three key aspects. First, most studies have estimated the payoffs to states' investment in agricultural research, ignoring the investment made by the central government, which is as high as 40% of the total investment. We have used their combined investment to estimate the payoff. Further, we have used an updated dataset up to 2020-21.

Second, there is little empirical evidence on the payoff to investment in agricultural extension, which is essential for disseminating technologies, innovations, and information. Based on a meta-analysis of limited studies from developing countries, Mogues et al. (2012) have found a median internal rate of returns of 41% on investment in agricultural extension. Studies from India based on cross-section household data have shown that farmers' access to technical advice and information can raise farm income by 10-20% (Birthal et al., 2015; Kumar et al., 2019; Birthal et al., 2022). In this study, we have also estimated the payoff to investment in agricultural extension, which is quite attractive.

Our study's third and most important contribution is that, unlike most other studies that assessed the payoff to investment in research for the agricultural sector, we have simultaneously estimated the payoffs to investment in its two important sub-sectors, i.e., crops and livestock. It may be noted that disciplinary research differs in the gestation period, resource requirement, and efficiency. Recently, some studies have estimated the internal rate of returns to investment in animal science research (Kathayat et al., 2023; Nevondo et al., 2019). Kathayat et al. (2023) estimate it 41% for animal science research in India, and Nevondo et al. (2019) at 32% for beef cattle research in South Africa. Our estimates show significant differences in the payoffs to investment in research across sub-sectors. For every rupee spent, there is a payoff of Rs 20.81 from animal science research, almost double that from crop science research. On the other hand, the payoff to investment in livestock extension is estimated at Rs 6.17, nearly two-thirds of that in crop extension.

Understanding the patterns of R&D investment at sub-sector levels, its distribution between research and extension, and the payoffs from it is essential for informed decisions on resource allocation and prioritizing research and development agenda to derive maximum economic, social, and environmental benefits from the investment.

8 Conclusions and Implications

Since the advent of the Green Revolution in the mid-1960s, India's agri-food system has undergone a steady transformation, which ensured nation's food security, empowered millions of people to escape poverty and undernutrition traps, boosted the country's resilience to unforeseen shocks, and enhanced its capacity to export. This could be possible because of the technical progress in agricultural sector and enabling policies. However, looking towards the growing demand for food and other agricultural products and the future challenges to their production amidst little scope for expansion of agricultural land, it is imperative to invest more in agricultural R&D and prioritize it across disciplines or sub-sectors and regions to maximize economic, social, and environmental benefits.

This study has examined the level and trend in investment in agricultural R&D, its allocation across sub-sectors, and assessed the economic returns on it. The main findings are summarized below.

- Investment in agricultural R&D (including public and private) has increased almost five-fold over the past four decades. Nevertheless, the annual growth in research investment has decelerated to 4.4% during 2011-2020 from around 6.4% during 1981-1990, primarily due to sluggish growth in public investment and significant deceleration in the growth of private investment. However, there is little crowding-out effect of private investment on public investment in agricultural research. On the other hand, the growth in extension investment has been volatile.
- Investment in agricultural R&D pays rich dividends. For every rupee invested in agricultural research, there is a payoff of Rs 13.85, and in agricultural extension, Rs 7.40.
- There are significant differences in the payoffs to investment at sub-sector levels. At a similar level of investment, the payoff from animal science research is Rs 20.81 compared to Rs 11.69 from crop science research. On the other hand, the payoff to investment in crop extension (Rs 10.80) is significantly higher than that in livestock extension (Rs 6.17).

- Agriculture R&D is largely public-funded. During 2011-2020, central and state governments respectively contributed 33.8% and 58.5% of the total investment in agricultural R&D, and the private sector accounted for the rest (8%).
- Although the proportion of AgGDP spent on research has increased, it remains less than the global average. From 2011 to 2020, India spent 0.61% of its AgGDP on research, which is about two-thirds of the global average of 0.93%. The proportion of AgGDP spent on extension services was 0.16%. In 2020-21, it spent 0.54% of AgGDP on research and 0.11% on extension.
- There are significant regional disparities in R&D investment. From 2011 to 2020, Odisha, Rajasthan, Madhya Pradesh, West Bengal, and Uttar Pradesh, which share 43% of the country's net sown area, spent less than 0.25% of their AgGDP on agricultural research. On the other hand, Jammu & Kashmir, Himachal Pradesh, Bihar, Uttarakhand, Kerala, and Assam spent more than 0.80% of their AgGDP on R&D.
- Research accounts for about 80% of the total R&D investment. However, there are significant regional differences. Research shares 80% or more of the total R&D investment in Andhra Pradesh, Karnataka, Uttarakhand, Jammu & Kashmir, Himachal Pradesh, Rajasthan, and Gujarat. Its share is less than 60% in Haryana, West Bengal, Madhya Pradesh, Uttar Pradesh, Bihar, Jharkhand, Goa, Sikkim, Tripura, Nagaland, Manipur, and Meghalaya.
- The portfolio of agricultural R&D remains heavily biased towards crops. Livestock and natural resources receive significantly less. Nonetheless, there is a gradual shift in the central government's priorities from crops to livestock, fisheries, and natural resources. The reverse holds in the case of states. Nonetheless, the R&D portfolio of southern states is relatively balanced.

These findings provide valuable insights into the role of agricultural research and extension in transforming the agri-food system. This will help decision-makers justify more investment in agricultural R&D and its prioritization across subsectors, disciplines, commodities, and regions.

- The increasing demand for food and non-food commodities amidst the growing challenges of climate change and natural resource degradation reinforces the need for more investment in agricultural research to transform the agri-food system sustainably. By 2030, investment in research should match the global average of about one percent of AgGDP.

- Since private investment has no crowding effect on public investment, the governments should facilitate private and philanthropic investment in agricultural research. The private sector may develop its research capacity or support public-sector research through collaborations and partnerships. Note that research involves significant fixed costs and a long gestation. India's public agricultural research system is relatively well-developed in infrastructure and skilled human resources, which can be leveraged to strengthen public-private partnerships and collaborations.
- The comparatively high payoff to investment in animal science research reinforces the need for more public-sector investment in it. Given the more egalitarian distribution of livestock resources and the high-income elasticity of demand for animal-source foods, the social payoffs (i.e., reduction in poverty and undernutrition) from increased investment in animal science research are expected to be quite large.
- Looking towards the increasing negative externalities to land, water, biodiversity, and the environment and the growing threat of climate change, there is an urgent need for more research on managing natural resources, climate adaptation, and mitigation.
- Odisha, Rajasthan, West Bengal, Madhya Pradesh, and Uttar Pradesh need to invest more in agricultural R&D, while others need to improve the conditions that facilitate the adoption of technologies to realize the impacts of investment.
- Finally, underinvestment in extension may hamper realizing the potential benefits of investment in research. Hence, investment in research should be complemented by more investment in extension.

Science, technology, and innovations in and for agriculture have considerable potential to address multiple challenges, including improving agricultural productivity and resilience to climate change and preserving natural resources, biodiversity, and the environment. Leveraging their potential requires investment in and for agricultural research, and policy support. *The investment in agricultural research made today will be crucial to shaping the future trajectory of agricultural growth for a prosperous, healthy, nutritionally secure, and poverty-free India*.

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Appendix Tables

Table A5.1. Decade-wise average investment in agricultural R&D in states, 1981-2020.

State	Total investment (Rs million/annum)				Share of research (%)			
	1981-1990	1991-2000	2001-2010	2011-2020	1981-1990	1991-2000	2001-2010	2011-2020
Andhra Pradesh	921	1918	2960	8681	90.7	90.5	93.5	96.4
Arunachal Pradesh	51	96	74	279	24.8	56.9	32.9	66.2
Assam	903	1074	1892	3000	67.1	58.9	57.3	71.8
Bihar	1595	1848	2000	8171	37.1	42.1	55.9	37.7
Chhattisgarh	NA	NA	441	1259	NA	NA	74.9	70.7
Goa	20	26	41	68	58.0	53.5	45.5	28.3
Gujarat	1435	2222	2923	6423	62.6	64.7	76.8	81.5
Haryana	765	1270	2942	4928	88.7	74.5	56.0	53.7
Himachal Pradesh	364	679	1088	1797	73.7	73.3	85.3	83.1
Jammu & Kashmir	439	660	1571	2463	61.4	34.7	67.2	83.4
Jharkhand	NA	NA	989	1535	NA	NA	56.0	59.9
Karnataka	782	1538	2389	5395	81.9	88.8	90.1	87.4
Kerala	732	1421	1486	5051	88.2	93.8	89.7	67.0
Madhya Pradesh	518	903	1203	2889	68.0	77.9	69.9	42.2
Maharashtra	3157	4642	5633	8810	65.8	68.0	80.6	78.8
Manipur	84	101	70	83	69.5	51.2	39.4	50.0
Meghalaya	74	106	146	250	44.8	47.6	51.6	45.3
Mizoram	21	29	45	174	27.3	15.1	24.5	68.0
Nagaland	78	60	146	192	81.2	78.4	69.0	50.7
Odisha	483	554	459	767	49.9	65.0	77.3	79.2
Punjab	1062	1400	1837	3481	90.4	95.9	95.4	79.1
Rajasthan	1086	1124	1203	1955	42.0	72.5	85.6	82.4
Sikkim	30	37	32	54	57.7	59.1	28.0	0.0
Tamil Nadu	1621	3594	4279	7858	41.8	48.8	57.4	70.9
Tripura	45	36	186	424	17.0	23.1	30.9	2.5
Uttar Pradesh	1652	3365	3387	5745	74.3	50.2	54.2	38.0
Uttarakhand	NA	NA	972	1538	NA	NA	93.0	85.8
West Bengal	1187	1091	1695	2905	53.6	72.0	60.9	44.1

Source: As for table 3.1.

Table A5.2. Research intensity in states

State	Research investment (% of AgGDP)				Research investment (Rs/ ha of gross cropped area/ annum)			
	1981-1990	1991-2000	2001-2010	2011-2020	1981-1990	1991-2000	2001-2010	2011-2020
Andhra Pradesh	0.26	0.34	0.35	0.40	67	133	211	620
Arunachal Pradesh	0.12	0.37	0.11	0.28	55	215	84	582
Assam	0.39	0.29	0.42	0.56	162	160	273	532
Bihar	0.22	0.24	0.26	0.63	57	80	148	413
Chhattisgarh	NA	NA	0.17	0.23	NA	NA	58	145
Goa	0.10	0.09	0.11	0.07	79	83	88	125
Gujarat	0.28	0.34	0.37	0.41	89	133	193	422
Haryana	0.31	0.27	0.35	0.34	122	158	258	406
Himachal Pradesh	0.60	0.76	0.87	1.12	274	515	980	1612
Jammu & Kashmir	0.46	0.29	0.90	1.20	259	212	766	1639
Jharkhand	NA	NA	0.28	0.31	NA	NA	340	517
Karnataka	0.14	0.20	0.33	0.47	54	112	173	387
Kerala	0.36	0.43	0.34	0.63	221	443	470	1303
Madhya Pradesh	0.08	0.13	0.13	0.07	15	30	42	51
Maharashtra	0.34	0.35	0.40	0.41	101	148	202	291
Manipur	0.31	0.23	0.11	0.12	307	236	88	104
Meghalaya	0.24	0.25	0.26	0.30	142	199	261	355
Mizoram	0.11	0.04	0.08	0.44	84	44	95	771
Nagaland	0.84	0.29	0.29	0.19	328	188	241	192
Odisha	0.08	0.12	0.10	0.09	26	40	42	133
Punjab	0.03	0.06	0.28	0.31	132	173	222	351
Rajasthan	0.15	0.17	0.17	0.11	26	41	49	65
Sikkim	0.64	0.60	0.21	0.00	131	170	74	0
Tamil Nadu	0.23	0.40	0.46	0.49	100	263	424	1029
Tripura	0.03	0.03	0.13	0.01	18	22	14	12
Uttar Pradesh	0.16	0.16	0.13	0.10	49	65	48	58
Uttarakhand	NA	NA	0.95	0.92	NA	NA	752	1230
West Bengal	0.16	0.12	0.11	0.08	78	87	108	126

Source: As for table 3.1.

Table A5.3. Extension intensity in states

States	Extension investment (% of AgGDP)				Extension investment (Rs/ ha of gross cropped area/ annum)			
	1981-1990	1991-2000	2001-2010	2011-2020	1981-1990	1991-2000	2001-2010	2011-2020
Andhra Pradesh	0.03	0.03	0.02	0.02	7	14	14	24
Arunachal Pradesh	0.39	0.30	0.24	0.15	180	173	186	306
Assam	0.19	0.20	0.31	0.24	80	111	204	208
Bihar	0.38	0.33	0.20	0.68	96	109	116	673
Chhattisgarh	NA	NA	0.05	0.10	NA	NA	20	65
Goa	0.07	0.08	0.13	0.16	57	72	134	318
Gujarat	0.16	0.18	0.12	0.09	53	72	60	96
Haryana	0.04	0.09	0.26	0.30	16	53	202	350
Himachal Pradesh	0.21	0.29	0.15	0.22	98	187	169	329
Jammu & Kashmir	0.29	0.52	0.44	0.25	162	398	463	353
Jharkhand	NA	NA	0.21	0.20	NA	NA	266	347
Karnataka	0.03	0.02	0.04	0.07	12	14	19	56
Kerala	0.05	0.03	0.04	0.30	30	29	55	645
Madhya Pradesh	0.04	0.04	0.05	0.09	7	8	18	70
Maharashtra	0.18	0.16	0.09	0.11	52	70	49	80
Manipur	0.14	0.22	0.16	0.12	135	241	181	101
Meghalaya	0.30	0.28	0.24	0.35	178	218	245	431
Mizoram	0.28	0.22	0.27	0.15	219	256	337	319
Nagaland	0.19	0.08	0.13	0.17	75	52	116	183
Odisha	0.08	0.07	0.03	0.03	26	22	14	33
Punjab	0.00	0.00	0.01	0.08	14	7	11	93
Rajasthan	0.21	0.07	0.03	0.02	37	16	8	14
Sikkim	0.50	0.42	0.46	0.36	97	120	185	376
Tamil Nadu	0.33	0.41	0.37	0.20	139	277	319	423
Tripura	0.13	0.09	0.27	0.58	88	76	347	861
Uttar Pradesh	0.05	0.16	0.11	0.15	17	65	61	134
Uttarakhand	NA	NA	0.08	0.14	NA	NA	56	210
West Bengal	0.14	0.05	0.07	0.11	67	34	71	168

Source: As for table 3.1.

Table A5.4. Percent share of sub-sectors in research and extension investment, 2011-2020

State	Research				Extension			
	Crops	Livestock	Fisheries	Natural resources	Crops	Livestock	Fisheries	Natural resources
Andhra Pradesh	67.1	25.8	3.6	3.4	98.5	0.8	0.4	0.3
Arunachal Pradesh	60.4	37.7	1.0	0.8	74.9	18.1	2.0	5.1
Assam	98.2	0.1	0.7	1.0	78.3	7.2	14.4	0.1
Bihar	92.3	6.8	0.2	0.7	99.3	0.5	0.2	0.03
Chhattisgarh	97.3	1.4	1.3	0.0	52.2	40.7	7.0	0.1
Goa	91.6	5.1	2.5	0.8	68.7	24.3	7.0	0.0
Gujarat	94.9	4.7	0.4	0.0	93.4	3.9	2.7	0.02
Haryana	99.7	0.0	0.3	0.0	98.9	0.1	0.8	0.2
Himachal Pradesh	88.0	11.9	0.1	0.0	98.5	0.4	0.5	0.6
Jammu & Kashmir	91.1	6.9	1.0	1.0	98.4	1.4	0.0	0.2
Jharkhand	100.0	0.0	0.0	0.0	97.0	3.0	0.0	0.0
Karnataka	56.8	37.0	5.5	0.6	91.1	5.9	1.3	1.7
Kerala	57.6	21.9	6.4	14.1	65.4	27.1	6.5	1.0
Madhya Pradesh	88.1	6.4	0.3	5.2	79.1	20.2	0.5	0.2
Maharashtra	91.2	3.6	3.7	1.5	55.2	43.4	1.3	1.1
Manipur	64.4	19.0	7.7	8.4	87.7	2.9	6.7	2.7
Meghalaya	61.7	29.6	4.9	3.8	70.4	5.4	3.1	21.1
Mizoram	99.1	0.7	0.1	0.1	69.6	24.9	1.3	4.2
Nagaland	62.1		2.8	7.0	91.8	1.7	3.8	2.7
Odisha	98.1	0.2	1.7	0.0	70.7	12.3	11.7	5.3
Punjab	80.5	19.0	0.1	0.4	75.4	9.7	11.6	3.3
Rajasthan	99.4	0.6	0.0	0.0	89.2	8.2	0.1	2.5
Sikkim*	-	-	-	-	79.5	20.4	0.1	0.0
Tamil Nadu	58.9	34.6	6.3	0.2	97.1	0.03	1.0	1.8
Tripura	63.2	18.1	17.0	1.7	90.2	9.4	0.3	0.1
Uttar Pradesh	84.2	14.6	0.7	0.5	97.7	1.2	1.0	0.08
Uttarakhand	89.0	10.3	0.2	0.5	99.1	0.5	0.2	0.2
West Bengal	93.9	3.9	1.4	0.8	94.3	1.0	4.3	0.4

** No data available on research expenditure for Sikkim.*
Source: As for table 3.1.

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