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Agricultural Productivity and Food Security: Role of Public and Private Sector Investment in Research and Development

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Abstract: The aim of this study is to observe the impact of public and private agricultural research and development (R&D) investment on agricultural productivity and food security. To testify aforementioned goal, we use worldwide data collected from Food and Agricultural Organization (FAO), United State Department of Agriculture (USDA), and World Development Indicators (WDI). The study time span is from 1990 to 2014. By using different control variables, we found positive and statistically significant impact of both public and private agricultural R&D investment on agricultural productivity and food security. Furthermore, private sector agricultural R&D investment has higher impact, as compare to public sector agricultural R&D investment. However, both types of agricultural investments encourage total factor productivity. These results are further verified by using different proxies for agricultural productivity and food security. Study implications suggest that, R&D investment in the field of agriculture is very important for long term agricultural productivity and food security.

Keywords: Public Agricultural R&D, Private Agricultural R&D, Agricultural Productivity, Food Security.

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1 Introduction

Due to globalization, innovation has become of greater interest, especially in agriculture sector (Feder et al., 1985; Ghadim and Pannell. 1999; Lapple et al., 2016; Khanna et al., 2017). There is increasing desire for innovation is to reduce the cost of agricultural production along with sustain/improve quality, efficiency and effectiveness (Godfray et al., 2010; Fan et al., 2012; Levidow et al., 2014; Midmore, 2017). As per the word of Shy (1995), innovation is the tool to identify, generate, develop, improve, adopt and commercialize new products or processes. This definition broadly explains all possible aspects of innovation and technological spillover. Research and development activities are the key to introduce above stated procedures through which an entity produces innovation, satisfies consumer needs and complies environmental regulations (Ghazalian and Furtan, 2007; Acosta et al., 2015;). According to the past studies, research and development (R&D) investment is the primary source to increase total factor productivity in both industrial and agricultural sectors (Coe and Helpman, 1995; Mullen et al., 2008; Alene, 2010).

R&D investment is a crucial element to foster agricultural productivity and growth. As like Alston et al. (1999), reported that during 20th century growth and improvement in agriculture sector is based on agricultural R&D investment and the policies to regulate these investments. The agricultural sector is especially important because it vertically links with other sectors as well. Agriculture sector is intensively competitive and large part of agricultural R&D comes from public sources. Agricultural innovations are not only beneficial for agro-productivity and growth but also good for other linked sectors like farm machinery, pesticide industry, fertilizer units etc. (Gopinath and Roe, 2000). It is acceptable among researchers and economists that agricultural growth and productivity are important to satisfy global food requirements (Pardey et al., 2013; Alston and Pardey, 2014). Immobility between global food production and reduction in growth rate caused serious threat for global food security (Fan et al., 2012). There are many factors that participate in this issue but among all, stagnation or reduction in R&D investment is the main reason for such hazard. In the decade of 1990s, total agricultural R&D investment among developing countries increased by 2.1% per year (from 3.3 billion dollar to 3.9 billion dollar). These investments were largely contributed by Asian region (3.5%) followed by African region (1.9%) (Jack et al., 2014).

Agricultural R&D that invests today will be beneficial for future productivity, growth and food security. Recent literature have determined that to fulfill the future demand of agro-products, it is required to foster agriculture productivity by 60% to 100% within the time frame of 2005 to 2050 (Tilman et al., 2011; Ray et al., 2013). Worldwide food availability depends on agricultural productivity growth, food accessibility, utilization as well as stability, which not just relies on traditional inputs like arable land, but also on R&D related activities and innovations (Pardey et al., 2013). As explained earlier, public R&D is considered as key tool for agricultural R&D activities and technology but the new trend shows that such investment becomes stagnant or even decline in different regions and countries around the world (Beintema and Stads, 2008). However, private sector is playing its significant role to increase agricultural productivity and growth through R&D investment and technological innovation. Many past studies identified such role of private agricultural R&D investment to increase in crop productivity, innovation and growth among developed (Huffman and Evenson, 2008) and developing countries (Evenson et al., 1998; Ramaswami et al., 2002).

Food security is directly linked with availability and supply of food. According to the past studies of Avila and Evenson (2010) and Fuglie (2016), agricultural R&D is an important tool to foster agro-productivity and food security. Moreover, Pardey et al. (2013) reported that agricultural R&D investment conducted in USA has positive impact on productivity and growth not only in USA but also globally via technological changeover. Johnson (2000) pointed out world population trend since 1960 and agricultural production. He explained that as the world population increasing, it is required to enhance agricultural productivity by investing in agro R&D with the same pace to avoid food shortage. A better work environment in terms of R&D, off-farm employment etc. would enhance productivity and cope food insecurity situation (Ahmed et al., 2015).

Perez and Rosegrant (2015) conducted an analysis to examine the effect of research and development activities on world's price structure, agricultural productivity and food security. Author used three different types of R&D strategies (gradual, accelerated and developing countries TFP increase) and found positive relationship among all said indicators. Kristkova et al. (2016) evaluated the impact of government R&D spending on agricultural productivity and food security. The results disclosed positive relationship among stated indicators. However, recently public R&D investments are not enough to fuel agricultural productivity at the standard expected base level (2000s). Lee et al. (2017) estimated the role of agricultural R&D investment on food security. Authors used dataset consists of 822 observations from 41 countries within the period of 1981 to 2009. The results demonstrated U shape relationship between R&D investment and food security. Results also explained that increase in land productivity would influence food security. Better market access also leads to enhanced farmers' earning as well as food security (Ahmed et al., 2016).

Agricultural research and development is very important for increasing agriculture productivity and ultimately food security situation. Therefore, the objectives of this study are to investigate the impact of agriculture R & D on agricultural productivity as well as on food security. Furthermore, this study identifies the divergence among public and private R&D investment and their subsequent impact on agricultural productivity and food security. Most of the past studies are only restrict to one country or one source of R&D investment. But this study is novel in term of twofold aspects. Firstly, rich dataset is used and secondly, both public and private R&D investments are considered.

2. Materials and Methods

2.1 Hypothesis development

The main role of agriculture is to produce food. However, along with food production it has to perform multiple functions like maintain rural society, protect environment and secure present and future demand of food (Lee et al., 2017). Several prior research studies claimed that agricultural R&D investment enhances productivity which subsequently strengthens food security (Pardey et al., 2006; De Janvry and Sadoulet, 2009). Additionally, past literature evaluate the direct impact of agricultural

R&D on food security. These studies argued that R&D investment in the field of agriculture enhances innovation in shape of pesticide, fertilizer, farm machinery etc. that increases agricultural production with low cost. Such enhancement in production and detraction in cost will ultimately effect on food availability and security.

In 20th century, agricultural R&D investment contributes in innovation regarding agricultural/food sector around the world. These innovations increase not only agricultural productivity but also reduce poverty and maintain food security through abundant and cheaper production (cultivation), and reduce food prices shocks. Public and private R&D investment fuels to increase such productivity along with affordable prices, which subsequently improve living standards and reduce food shortage. Many researchers like Alston and Pardey (2013) are now agreed to a point that R&D is the baseline for innovation, which usually happens in developed countries that determines development and growth. This argument is also valid in agrarian countries around the world, that R&D investment enhances food supply and productivity growth (Alston and Pardey, 2013).

In agricultural sector R&D foster growth and total factor productivity (TFP) by developing, adopting and diffusing new and advanced and ultimately leading to increased crop production (Perez and Rosegrant, 2015). According to past studies, contrary to the other traditional inputs like material, labor and capital, R&D categorizes as environmental factor, which impact production environment (Zhang et al., 2012). Agricultural R&D investment and agricultural policies not only foster productivity but also stimulates living standards and ultimately economic growth. Total factor productivity growth is directly linked with agricultural R&D investment which depends upon the rate of return on such investment (Mullen et al., 2008). Growth in agricultural productivity is considered as important element for an agro based economy. One way to stabilize and improve such growth is to fuel agricultural R&D investment. Past studies also provide theoretical and empirical based relationship among R&D investment and agricultural growth and TFP (Grossman and Helpman, 1991; Shamsadini et al., 2012).

In recent years agricultural R&D investment conducted by private entities increase tremendously. This kind of investing activities increase the productivity and quality of goods. Additionally, such private participation in agricultural sector reduces the cost of cultivation, which makes the product affordable and price competitive (Alfranca and Huffman, 2003). Technological development in agricultural sector is considered as the key element to sustain and improve long-term productivity. R&D investment creates knowledge, ideas and innovations that subsequently alter cultivation and production processes and stimulate productivity (Mozumdar, 2012). According to Antle and Capalbo (1988) new technological improvement is the result of knowledge, research and innovation. Therefore, R&D investment in agricultural sector is considered as the most important tool for productivity growth.

The impact of agricultural R&D investment on food security can be identified through two ways. Firstly, agricultural R&D investment participates in the improvement of productivity growth and efficiency, which subsequently enhance food security. The sole purpose of agro related R&D investment is to foster agricultural productivity and maintain/ improve production quality. Such relationship is tested in prior literature in different countries (developed and developing). Secondly, agricultural R&D investment adds to the effectiveness of domestic agriculture products, so in return their supply increases that eventually improve food security. Agricultural R&D investment develops new varieties and value added agro products, which help to minimize the fear of food danger (Lee et al., 2017).

There are numerous challenges to attain long run sustainable agricultural productivity and food safety. On one hand, there is ongoing increase in demand of food due to nonstop growth in population, and enhancement in the lifestyle of developing nations. On other hand, there are constraints on supply side because of certain restrictions like limited arable area, change in climate, migration of rural population to urban societies etc. Moreover, agricultural productivity growth is also extremely challenging because of land and water scarcity. In this situation, agricultural R&D investment became more important for the development of new technologies to foster productivity and food supply by considering all above stated challenges (Hu et al., 2011). By above mentioned literature and arguments, we can hypothesize that;

H_1: Agricultural R&D investments (public and private) have positive impact on agricultural productivity.

H_2: Agricultural R&D investments (public and private) have positive impact on food security.

2.2 Data Processing

To examine the impact of private and public agricultural R&D investment on agricultural productivity and food security, we use worldwide data from different sources i.e. Food and Agricultural Organization (FAO), United State Department of Agriculture (USDA), and World Bank (WDI). This study is based on time series secondary data analyses from 1990 to 2014 (25 years). All variables used to testify above stated hypotheses are worldwide indicators. For statistical analyses, we used ordinary least square (OLS) along with robust standard error technique. To test study sample regarding unit root and multicollinearity, we used Augmented Dickey Fuller Test and Pearson Correlation Test respectively.

2.2.1 Measurement of variables

2.2.1.1 Dependent variables

We use agricultural growth of TFP to estimate agricultural productivity. To gather data on said indicator, we used as described by USDA. This indicator calculates worldwide across study period (1990-2014). To measure global food security, we use an indicator, which represents per capita food supply variability. Data on this variable is collected from FAO. Same like agricultural productivity indicator, this variable is also global level indicator and represents overall food security in the world.

2.2.1.2 Independent variables

Based on hypotheses developed in chapter 3, we measure agricultural R&D investment conducted by both private and public sources. To measure public agricultural R&D investment we use worldwide data of FAO issued in 2016 report. Due to data unavailability constraints, we only get data from 2000 to 2014. Moreover, indicator for private agricultural R&D investment is only possible through dynamic study of Fuglie (2016), in which author explained the growing trend of private sector agricultural R&D investment globally, by using crop R&D and farm machinery R&D. We calculate growth rate among such investment to analyze the impact of private R&D investment on agricultural productivity and food security.

2.2.1.3 Control variables

To affirm the study objectives, we used several control variables (used as worldwide) at national level which have impact on agricultural productivity and food security. These variables are agricultural land, agricultural input, water resources, gross domestic product, and irrigated area. We measure agricultural land as percentage of total land, agricultural input as growth rate of inputs, water resources as percentage of population have access to improved water resources, gross domestic product as GDP growth, and lastly irrigated area as growth in irrigated area. All data regarding control variables are gathered through WDI and USDA.

2.2.2 Empirical Models

To prove study hypotheses we develop four econometric models. First two models are used to evaluate the impact of public and private agricultural R&D investment on productivity (H_1). Additionally second two models are used to verify the relationship among public/private agricultural R&D investment and food security (H_2). To avoid biased estimation from regression analyses, we use robust standard error technique and test for unit root and collinearity among variables.

Table 1: Variable Definition

Variable	Notation	Measurement	Source
Agriculture Total Factor Productivity	ATFP	Growth rate in agriculture total factor productivity	USDA
Food Supply	FSP	Variability in per capita food supply	FAO, (2016)
Public Agricultural R&D investment	GARD	Growth rate in public agricultural R&D investment	FAO, (2016)
Private Agricultural R&D investment	PARD	Growth rate in private agricultural R&D investment	Fuglie (2016)
Agricultural Land	AL	Percentage of total land use for agriculture	WDI
Agriculture Input	AI	Growth rate in total agricultural inputs	USDA
Water Resources	WR	Percentage of population have access to improved water resources	WDI
Gross Domestic Product	GDP	Annual growth rate in gross domestic product globally	WDI
Irrigated Area	IA	Growth rate in irrigated area	USDA

FAO report issued on 16th December 2016.
Data of WDI are extracted from World Bank database(http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators)
USDA data is taken from United States Department of Agriculture website(https://ndb.nal.usda.gov/ndb/)

Table 2: Descriptive Statistics

Variable	Obs.	Mean	S.D.	Min	Max
Private Agricultural R&D investment	24	0.0482	0.0411	-0.0348	0.1285
Public Agricultural R&D investment	13	0.0865	0.1622	-0.1568	0.3874
Agriculture Total Factor Productivity	24	0.0152	0.0059	-0.0023	0.0273
Food Supply	22	2.7007	0.8900	1.0986	4.1744
Agricultural Land	25	37.9509	0.5080	37.3497	39.4701
Agriculture Input	24	0.0075	0.0061	-0.0055	0.0211
Water Resources	25	83.5708	4.4761	76.0770	90.5523
Gross Domestic Product	25	2.8083	1.3250	-1.7005	4.4757
Irrigated Area	24	0.0100	0.0043	0.0039	0.0244

$$ATFP_t = \beta_0 + \beta_1 PARD_t + \beta_2 AL_t + \beta_3 AI_t + \beta_4 WR_t + \beta_5 GDP_t + \beta_6 IA_t + \varepsilon_t \quad [1]$$

$$ATFP_t = \beta_0 + \beta_1 GARD_t + \beta_2 AL_t + \beta_3 AI_t + \beta_4 WR_t + \beta_5 GDP_t + \beta_6 IA_t + \varepsilon_t \quad [2]$$

$$FSP_t = \beta_0 + \beta_1 PARD_t + \beta_2 AL_t + \beta_3 AI_t + \beta_4 WR_t + \beta_5 GDP_t + \beta_6 IA_t + \varepsilon_t \quad [3]$$

$$FSP_t = \beta_0 + \beta_1 GARD_t + \beta_2 AL_t + \beta_3 AI_t + \beta_4 WR_t + \beta_5 GDP_t + \beta_6 IA_t + \varepsilon_t \quad [4]$$

3. Results and Discussion

3.1 Descriptive Statistics

Table 2 explains the descriptive analyses of the variables used to analyze study hypotheses. According to the dataset, private agricultural R&D investment grows at the rate of 4.82% annually during the period of 1990 to 2014. On the other hand, public agricultural R&D investment rises with the annual rate of 8.65% during the period of 2000 to 2014. Agricultural total factor productivity shows a relatively lower growth rate of 0.0152 globally. However, variability in per capita food supply during the same period shows an average value of 2.70. Interestingly, percentage of total land use for agriculture, presents stable average rate of 37.95% with the minimum of 37.34% and maximum of 39.47%. Study dataset shows that, agricultural inputs growth increases with the annual rate of 0.75%, which is relatively lower as compare to growth in agricultural total factor productivity. Improved water resources available to population shows mean value of 83.57 percent with the lower percentage of 76.97 and higher of 90.55 %. Annual growth rate of GDP displays an average rate of 2.80% (minimum -1.70%, maximum 4.47%). Irrigated area increases with the annual rate of 1% globally during the study period.

3.2 Augmented Dickey Fuller test

In this study, we use time series data to evaluate the impact of public and private agricultural R&D investment on agricultural productivity and food security. There are various statistical issues in time series data that need to be rectified for reaching a robust conclusion. These issues are usually non-stationary and collinearity of variables. To examine stationary among variables, we use Augmented Dickey Fuller test and results are reported in Table 3. The results of Augmented Dickey Fuller shows that all variables used to analyze study hypotheses are stationary at level point.

Table 3: Augmented Dickey Fuller Test

Variables	Intercept/Trend	ADF- Stat	Critical Value		Stationary
			5%	10%	
Agriculture Total Factor Productivity	Intercept	-5.5002	-2.9980	-2.6380	Level
Food Supply	Intercept	-2.6710	3.0000	-2.6300	Level
Public Agricultural R&D investment	Intercept	-3.4690	-3.1449	-2.7137	Level
Private Agricultural R&D investment	Intercept	-2.7861	-2.9918	-2.6355	Level
Agricultural Land	Intercept	-3.5135	-2.9918	-2.6355	Level
Agriculture Input	Intercept	-4.0640	-2.9980	-2.6387	Level
Water Resources	Intercept	-7.8265	-3.0123	-2.6461	Level
Gross Domestic Product	Intercept	-4.2264	-2.9918	-2.6355	Level
Irrigated Area	Intercept	-4.5618	-2.9980	-2.6387	Level

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Table 4: Correlation Matrix of Variables

	PARD	GARD	ATFP	FSP	AL	AI	WR	GDP	IA
PARD	1.0000								
GARD	-0.1057	1.0000							
ATFP	0.5039	0.1752	1.0000						
FSP	-0.1523	0.4092	-0.1467	1.0000					
AL	-0.1337	-0.2701	-0.1326	0.0191	1.0000				
AI	-0.3724	-0.0809	-0.9631	0.0900	0.1936	1.0000			
WR	0.5003	0.2217	0.6533	-0.3209	-0.7365	-0.5993	1.0000		
GDP	0.1329	-0.0780	-0.0765	-0.2697	0.8351	0.2578	-0.4431	1.0000	
IA	0.3157	-0.2076	0.5208	0.1912	0.5163	-0.4726	-0.0135	0.3453	1.0000

PARD (Private Agricultural R&D investment), GARD (Public Agricultural R&D investment), ATFP (Agriculture Total Factor Productivity), FSP (Food Supply), AL (Agricultural Land), AI (Agriculture Input), WR (Water Resources), GDP (Gross Domestic Product), IA (Irrigated Area)

3.3 Collinearity

We test for collinearity by using Pearson Correlation Matrix and results are reported in Table 4. This test is used to identify the possible existence of collinearity among dependent, independent and control variables that normally lead to biased and unreliable results. The estimates of this test (table 4) showed that there is no issue of collinearity among variable that fuels to erratic results.

3.4 Agricultural R&D and Agricultural Productivity

To evaluate the relationship between public and private agricultural R&D investment on agricultural productivity (H_1), we use OLS technique along with robust standard error to control for possible issue heteroskedasticity. Several indicators have impact on agricultural productivity (agricultural land, agricultural inputs, water resources, irrigated area and GDP) (Table 5). We found positive and statistically significant impact of public as well as private agricultural R&D investment on agricultural total factor productivity. According to the results, private agricultural R&D investment has higher impact as compare to public agricultural R&D investment. However, both types of agricultural investments encourage total factor productivity. These results indicate that agricultural R&D investment made by public or private sector enhances innovation which subsequently increases overall crop production, reduces cost of cultivation along with affordable prices for consumers. These results are consistent with hypothesis and past studies (Mullen et al., 2008; Perez and Rosegrant, 2015). There is a huge wheat yield gap exist among Pakistan and major other countries of the world (Akhtar et al., 2015), which can be minimized through R&D.

Table 5: Regression Analysis

	Agriculture Total Factor Productivity		Food Supply	
Private Agricultural R&D investment	0.0159*		8.9486***	
	(1.82)		2.77	
Public Agricultural R&D investment		0.0044**		1.8555**
		(3.35)		2.98
Agricultural Land	0.0006	0.0134**	-0.5389**	-4.5059**
	(0.52)	(2.78)	-2.08	-3.15
Agriculture Input	-0.8649***	-0.7834***	18.1957	18.3605
	(-11.18)	(-8.36)	0.59	0.45
Water Resources	0.0005***	0.0015*	-0.2420***	-0.5211*
	(5.35)	(2.41)	-5.09	-2.8
Gross Domestic Product	0.0002	-0.0002	-0.1169	-0.0255
	0.59	(-1.33)	-1.31	-0.36
Irrigated Area	0.2305*	0.1158	-40.6619	276.8476***
	(1.71)	(0.87)	-0.65	3.89
Constant	-0.0482	-0.6158**	13.3942***	21.1081**
	(-0.98)	(-2.62)	3.52	3.11
Number of observation	23	12	21	10
F-Stat	93.96	137.71	11.12	14.84
Prob> F	0.0000	0.0000	0.0001	0.0247
R-squared	0.915	0.9899	0.6335	0.8623

The values of variables are in growth rates. *significant@10%, **significant@5%, ***significant@1%.

Table 6: Regression Analyses (Robust Check)

	Agricultural Production Growth		Cereal Import Dependency Ratio	
Private Agricultural R&D investment	0.0159* (1.82)		-2.0593*** (-3.92)	
Public Agricultural R&D investment		0.0044** (3.35)		0.0279 (0.12)
Agricultural Land	0.0006	0.0134**	-0.3686***	0.0527
	(0.52)	(2.78)	(-14.15)	(0.02)
Agriculture Input	0.1351*	0.2166*	3.9391	-7.3736
	(1.75)	(2.31)	(0.88)	(-0.35)
Water Resources	0.0005***	0.0015*	0.0473***	-0.0206
	(5.35)	(2.41)	(5.07)	(-0.13)
Gross Domestic Product	0.0002	-0.0002	0.0341*	0.0030
	(0.59)	(-1.33)	(1.88)	(0.03)
Irrigated Area	0.2305*	0.1158	10.9667	-14.6282
	(1.71)	(0.87)	(1.07)	(-0.58)
Constant	-0.0482	-0.6158**	9.6345***	-0.2349
	(-0.98)	(-2.62)	(6.5)	(0.01)
Number of observation	23	12	19	8
F-Stat	16.81	13.92	192.13	0.16
Prob> F	0.0000	0.0055	0.0000	0.9510
R-squared	0.7441	0.8979	0.9079	0.426

The values of variables are in growth rates. *significant@10%, **significant@5%, ***significant@1%

As per control variables are concerned, all of them show positive/negative impact on total agricultural productivity. More specifically, growth in agricultural land enhances total agricultural productivity growth (Fan, 1991; Irz et al., 2001; Foster and Rosenzweig, 2004; Coelli and Rao. 2005; Budzianowski, 2016). Theoretically agricultural growth may induce more area under cultivation. However, changing climatic conditions, land degradation rapid urbanization etc are major restrictions for expansion of area under agricultural production (Lambin et al., 2001; Eric et al., 2003; Rudel et al., 2009; Dias et al., 2016; Tobias et al., 2016; Erb et al., 2017). In any case agricultural growth ultimately fosters productivity. Surprisingly, agricultural inputs growth reduces agricultural total factor productivity. These possible results indicate that except developed countries other countries are still following old and traditional mechanism for agricultural purposes, which reduce agricultural total factor productivity. Results also suggest that increase in percentage of population that has access to improve water resources will increase agricultural productivity. Same like, increase in global irrigated land enhances overall agricultural total factor productivity.

3.5 Agricultural R&D and Food Security

To estimate the impact of public and private agricultural R&D investment on food security (H_2), we use food supply as a proxy for food security. We also used diverse range of control variables and robust standard error technique to find concrete results. As reported in table 5, after using control indicators, we found positive and statistically significant impact of both public and private R&D investments on food security. In more detail, private sector agricultural R&D investment has higher impact as compare to public agricultural R&D investment. These results verify that agricultural R&D investment develops new and effective mechanism to increase the supply of food with affordable prices that subsequently enhance global food security. These results are in line with study hypothesis and prior literature (Pardey et al., 2006; De Janvry and Sadoulet, 2009).

3.6 Robustness Check

To check for the robustness of the results, we change the proxies to measure agricultural productivity and food security. For such analysis, we use agricultural production growth to estimate agricultural productivity, and Cereal Import Dependency Ratio as a measure for food security. According to the results (Table 6), public and private R&D investment fosters agricultural productivity and food security globally. These results confirm the prior findings as reported in Table 5, hypotheses of this study and parallel to prior literature (Avila and Evenson, 2010; Fuglie, 2016) that identify positive relationship among said indicators.

4. Conclusion

The objective of this study is to determine the impact of public and private agricultural R&D investment on agricultural productivity and food security. After using different control variables (agricultural land growth, agricultural inputs growth, water resources, irrigated area growth and GDP growth), we found that there are positive and statistically significant impact of public and private agricultural R&D investment on agricultural productivity and food security. More precisely, private sector agricultural R&D investment has higher impact on both agricultural productivity and food security, as compare to public agricultural R&D investment. These results are also verified by using different proxies for agricultural productivity and food security and consistent with past studies (Pardey et al., 2006; Mullen et al., 2008; De Janvry and Sadoulet, 2009; Perez and Rosegrant, 2015). These results show that, to increase global agricultural productivity and food security, it is needed to foster agricultural R&D investment by both public and private sectors. Policy implications suggest that governments have to invest and encourage public/private R&D investment in the field of agriculture to fuel innovations that subsequently enhance agricultural productivity and food security. This study is only limited to global environment within certain period. Future studies can be done by dividing sample into developed and developing countries, with different time span. Moreover, future studies can also be conducted by evaluating the impact of climate change on agricultural productivity and food security, and how agriculture R&D can hemp to mitigate climate change.

List of abbreviations: FAO: Food and Agricultural Organization; R&D, Research and Development; TFP, Total Factor of Productivity; USDA, United States Department of Agriculture; WDI, World Development Indicators.

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