CHAPTER THREE

Global volatility of public agricultural R&D expenditure

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1. Introduction

It was in the late 19th century that public agricultural research institutions were set up in the advanced industrialized nations of today. These paved the way for technological change and transformation in the agricultural systems of these countries (Ruttan, 1982). In the last 50–100 years, dramatic changes in agricultural productivity and production have taken place, driven in large part by investments in public and private agricultural research (Alston and Pardey, 2014). These increases in agricultural productivity have by and large occurred across the globe, encompassing high-income

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(Andersen and Song, 2013; Khan et al., 2017; Thirtle et al., 2008) as well as middle- and low-income countries (Adetutu and Ajayi, 2020; Fan et al., 2000; Suphannachart and Warr, 2011), and involving their respective public sector agricultural R&D organizations. Today, nearly all countries in some form or another have national agricultural research institutes (Fuglie, 2018).

Thus, public sector agricultural research and development (R&D) has played an important role in increasing agricultural total factor productivity (TFP) across countries (Fuglie, 2018; Rawat and Akter, 2020). These past patterns of growth in agricultural productivity have had important implications for food security and poverty (Alston et al., 2009a). In current times the role for agricultural R&D has expanded further. From boosting agricultural productivity and improving food security, agricultural R&D is now also viewed as a powerful means to ensure environmental sustainability and tackle climate change (Acevedo et al., 2018). The former through interventions and innovations that can minimize ecological damage while increasing productivity (Swaminathan, 2017); the latter through research that focusses on combatting potential threats and adverse effects arising from a mean rise in temperature, and also by mitigating the effects of global green-house gases resulting from agriculture (Lobell et al., 2013).

According to the 2019 Global Agricultural Productivity Report, in order to sustainably meet the needs of an estimated 10 billion people in 2050, global agricultural productivity would need to increase from the current average annual rate of 1.63% to a rate of 1.73% per annum (Steensland, 2019). Given the limited natural resources and degradation of the resources already in use (Fuglie, 2015), increases in agricultural productivity would need to accrue from intensification, i.e. by raising yield per hectare. This makes the role of public agricultural R&D in raising agricultural productivity critical. Thus, stagnant or declining levels of public investment in agricultural R&D put future agricultural productivity growth at risk (Fuglie, 2015).

Furthermore, the stability of agricultural R&D investments is also crucial. This is because agricultural R&D projects tend to be characterized by temporal lags and lengthy time horizons (Alston et al., 2000a,b). The long lag between when R&D investment takes place and when it comes to fruition, implies that if agricultural productivity is to be maintained or even increased, a stable and sustained level of agricultural R&D expenditure is critical (Cai et al., 2017; Goyal and Nash, 2017). Existing studies that assess the stability of public agricultural R&D expenditures in the context of Sub-Saharan African countries in the 2000s, have noted substantial volatility in public agricultural R&D spending in the region (Beintema et al., 2012;

Stads and Beintema, 2015). But not much is known about the stability or volatility in public sector agricultural R&D expenditures across regions and over time. Is volatility in public agricultural R&D expenditures specific to Sub-Saharan Africa? How stable is public agricultural R&D in other regions? How has volatility in public agricultural R&D expenditures changed over time? Are there are any temporal and spatial patterns that policy-makers and policy-planners need to be cognizant of given the "fundamental irreversibility" of agricultural R&D spending (Cai et al., 2017, p. 71)? It is these and other related questions that this chapter seeks to shed light on.

In order to address these questions, we assemble a dataset of public agricultural R&D expenditures between 1981 and 2014 for 112 countries. For the sake of comparability, we employ the method used by the only other existing studies dealing with volatility in public agricultural R&D expenditures (Beintema et al., 2012; Stads and Beintema, 2015), to calculate volatility for each country. The results indicate that the average global volatility in public agricultural R&D expenditure during this period is considerable, with the highest levels for Sub-Saharan Africa and the least for South Asia. Countries across income groups show an increase in public agricultural R&D volatility during the 1990s. In the subsequent decade of the 2000s all countries, barring high-income countries witness a decline in the volatility of public agricultural R&D expenditures. High-income countries, in contrast, show a steady increase in public agricultural R&D volatility over time. Although low-income countries continue to have the highest amount of public agricultural R&D volatility, it is lesser than it was in the past.

This chapter proceeds in the following fashion: the next section discusses the state of public agricultural R&D currently. This section describes the major shifts in the global landscape of agricultural R&D today, drawing on what the literature has to say about this and about volatility in R&D. The third section explains the data and methodology this chapter uses to estimate volatility in public agricultural R&D expenditure. The fourth section presents the results. The fifth section discusses these results and their implications. This is followed by a concluding section.

2. The state of public agricultural R&D today

2.1 A shift in the traditional bastions of agricultural research

In order to describe the current state of global public agricultural R&D, we draw on the research of Philip Pardey and his colleagues at the International

Science and Technology Practice and Policy (InSTePP) Center at the University of Minnesota. They note that the share of agriculture related R&D activities in total R&D investment is still quite low. In 2011, agriculture and food, accounted for roughly 5% of world-wide investment in all forms of R&D (Pardey et al., 2016). While the global landscape of agricultural R&D has changed over time, two developments in particular stand out—(i) a shift in agricultural R&D from the public sector to the private sector; and (ii) a shift away from the traditional top-spenders in agricultural R&D such as the United States, toward agriculturally important middle-income nations like China, India and Brazil (Alston and Pardey, 2020; Pardey et al., 2016).

Although agricultural R&D has historically been the reserve of the public sector because of its large associated fixed costs, long gestation periods, and public goods nature of R&D (in that it is non-excludable and non-rival) (Khanna et al., 1994); with the rise of intellectual property rights (IPR) in agricultural research and changes in the consumer market (Alston and Pardey, 2014; Pardey et al., 2006), the influence of private sector R&D in agriculture has gradually increased over time (Pardey et al., 2016). This is particularly salient in high-income countries where public agricultural R&D investment has grown considerably slowly in recent times (Fuglie, 2018; Heisey and Fuglie, 2018). In 2011, on average the private sector accounted for about 52.5% of the domestic research spending on crop breeding, pesticides, fertilizers, food technologies and informatics in high-income countries, an increase from 42% in 1980. Even in middle-income countries the share of the private sector in domestic agricultural research increased from 16% in 1980 to 35.5% in 2011 (Pardey et al., 2016). According to Fuglie (2016), globally private sector expenditure on agricultural R&D (excluding food industries) tripled over the last three decades, rising from $5.1 billion in 1990 to $15.6 billion by 2014 (Fuglie, 2016).

The other significant development related to global agricultural R&D has been the relatively slow growth in public agricultural R&D in high-income countries while middle-income countries have begun to invest more (Chai et al., 2019; Pardey et al., 2016). Using data on public agricultural R&D expenditure for a sample of 31 high-income countries, Heisey and Fuglie, find that on average the share of national public R&D expenditure devoted to agriculture reduced from around 9% in 1981–85 to 5.5% in 2009–13 (Heisey and Fuglie, 2018).

The lower relative level of domestic spending on public agricultural R&D in high-income countries is also reflected in a decline in their relative shares on the global stage. Between 1960 and 2011, high-income countries' share of public sector agricultural R&D in total global public agricultural R&D expenditure declined from 56% to 47%. At the same time the gap between public agricultural R&D spending in low-income countries versus middle- and high-income countries also widened (Pardey et al., 2016). In 2011, middle- and high-income countries together made up almost 97% of the global public sector agricultural R&D expenditure (Pardey et al., 2016), with low-income countries continuing to account for an exceptionally small proportion of the global public agricultural R&D (Pardey et al., 2018). In low-income countries a low level of public investment in agricultural R&D is of particular concern as these countries are also likely to lie outside the orbit of private interest (Pingali, 2010).

Thus, despite the significant economic returns associated with agricultural R&D expenditures (Alston et al., 2000b; Hurley et al., 2014), low income countries—regions with the highest rates of population growth and a greater dependence on agriculture—are also the places where the per capita investment in public agricultural R&D is among the lowest in the world. Roseboom (2002) argues that one of the primary reasons for underinvestment in public agricultural R&D in developing countries is the relatively smaller portfolio of profitable R&D projects they have to choose from. The other reasons he cites are the less precise information, higher uncertainty, less robust selection procedures, greater budget rigidity and a lack of political will and organizational capacity in society. Mogues (2015) explains the conundrum of underinvestment in public agricultural R&D by focusing on the political-economy factors that guide policy-makers' spending decisions. She identifies three specific political economy considerations in this respect–attributability of a public expenditure, its distributional properties and the temporal lag associated between allocation and final delivery of the product or service.

Attributability refers to the extent to which citizens are able to assess how far a policy-maker is responsible for a particular policy action and its outcome. Thus, policy-makers may prefer visible expenditures that can easily be connected to their decisions. For instance, in Mozambique it was found that public officials preferred to invest in large-scale irrigation schemes that were more visible, to small-scale schemes despite the weaker performance of the large-scale schemes (Mogues and do Rosario, 2016).

Distributional properties of a public expenditure determine who benefits from the expenditure and the relative strength of that group. The stronger an interest group the greater its ability to influence policy decisions in its favor. For example, agricultural producer groups are more organized and have a common interest as compared to citizens, and hence exert more influence on policy-making (Olson, 1985). Interactions between the government and interest groups can affect the form public expenditure takes. Using the case of a subsidy versus a transfer, Drazen and Limão (2008) argue that a government's bargaining power when interacting with an interest group is stronger if the public expenditure takes the form of a subsidy rather than a transfer. Since both the interest group and the government are aware of the fact that subsidies impose a greater tax burden and induce a dead-weight loss as compared to more efficient transfers, it gives the government greater room to demand more lobby goods from the interest groups in return for the subsidy (Drazen and Limão, 2008).

The temporal lag refers to the length of time between when the public investment initially takes place and when it comes to fruition. A long lag reduces the attributability of the investment to the policy-makers who took the decision to undertake it in the first place. Moreover, when politicians and public officials have a limited term in office then they have little to gain from investments that come to fruition long after they have left office (Mogues, 2015). Moreover, a long lag also increases the uncertainty associated with the possible impact of the investment (Cai et al., 2017).

As public agricultural R&D is characterized by long time horizons, the problem of attributability and a temporal lag are particularly salient for it. Further, the inherent uncertainty associated with R&D activity implies that it is not always certain who benefits from it (Alston et al., 2009b) and this prevents potential interest groups from coalescing to lobby for it. Uncertainty in terms of the ability to predict the economic potential of public agricultural R&D investments, also contributes to underinvestment on the part of the government (Roseboom, 2002). Thus, the more a government's thinking is dominated by expediency and short-term considerations the more likely it is to rely on the effects of previous research, leaving it to future governments to bear the brunt of current policies (Harris and Lloyd, 1991). Thus, a combination of these political and economic factors can skew policy-makers from investing in public agricultural R&D.

2.2 Volatility in R&D

The literature on public agricultural R&D does not have much to say with respect to its volatility. Although there is country-specific anecdotal evidence of the instability in public sector agricultural R&D, for example Niger (Stads et al., 2010) and Pakistan (IFPRI and PRAC, 2012), there have been few attempts to quantify and measure the extent of instability.

Consequently, there is also no empirical evidence related to the impact of volatility in public agricultural R&D expenditure on outcomes such as, agricultural innovation, agricultural productivity, welfare or food security.

Drawing on the literature related to volatility in R&D in general, we find evidence of the negative effects of R&D volatility on stock return in the private sector (Xiang et al., 2020). Wälde and Woitek (2004) analyze fluctuations in R&D expenditure in the private sector of G7 countries and find a positive correlation between economic growth and R&D expenditure (Wälde and Woitek, 2004). Similarly, volatility in public R&D in environmental technologies is seen to have an adverse impact on innovation (Johnstone et al., 2011). The ostensible contention of these and other papers that look at firm level behavior (for instance (Brown and Petersen, 2011; Kor and Mahoney, 2005)), is that R&D expenditures should be stable over time in order to maintain firm performance (Grabowski, 1968) and avoid large adjustment costs (Brown and Petersen, 2011).

The literature on macroeconomic volatility also provides some insights that can be deemed to be relevant to the study of volatility in public agricultural R&D expenditure and in support of the hypothesis that stability in expenditures is important for growth and welfare. For instance, Herrera (2007) identifies a positive relation between volatility in government spending and consumption volatility that results in a welfare loss, especially in low-income countries (Herrera, 2007). Studies on aid flows also find that their volatility slows down macroeconomic growth (Desai and Kharas, 2010; Fielding and Mavrotas, 2008; Hudson and Mosley, 2008).

Finally, volatility in public agricultural R&D expenditures may have consequences for research composition and output which could impact related areas such as food security and environmental sustainability. Thus, volatility in public agricultural R&D expenditures is expected to be a matter of significant concern and quantifying the extent of this volatility is a necessary first step before its impact can be assessed. We leave the question of the impact of volatility as a topic for future research and focus our attention in this chapter on measuring and analyzing the global volatility in public agricultural R&D expenditure between 1981 and 2014.

3. Estimating volatility in public agricultural R&D expenditure: Data and methods

3.1 Data

This chapter makes use of public agricultural R&D expenditure data that is compiled from three sources—Agricultural Science Technology Indicators

(ASTI, n.d.), Organization for Economic Cooperation and Development (OECD, n.d.) and the United Nations Educational, Scientific and Cultural Organization (UNESCO, n.d.). ASTI's definition of public agricultural R&D expenditure includes public spending on research on forestry, fisheries, livestock, other socio-economic aspects of primary agricultural production, as well as on-farm storage and processing of agricultural products (ASTI, 2017). This data is measured in constant 2011 PPP dollars (millions). The OECD database provides measures of gross domestic R&D expenditure by the government on agricultural and veterinary sciences in 2010 PPP dollars (million) (OECD, n.d.). UNESCO's "Science, technology and innovation" database measures government sector expenditure on R&D in agricultural and veterinary sciences (UNESCO, n.d.) in 2005 constant PPP dollars (in '000). In order to create a single harmonized series for public agricultural R&D expenditures values from each of the three data sources were expressed in billion PPP dollars (base 2005).[a]

ASTI data is chosen as the base data because of its greater coverage of low-income and middle-income countries and its reliance on self-conducted national survey rounds, in addition to secondary data. ASTI data is supplemented with data from OECD and UNESCO for countries where it is not available. In cases where OECD data and UNESCO data have comparable values, the series that has a greater number of observations for a given country, is chosen. For countries that have the same number of observations in the two series, and where the values between the two datasets differed noticeably, OECD data is chosen because the UNESCO data itself follows the OECD Frascati Manual guidelines in the first place and also references the OECD data for many of its observations.

For the sake of bench-marking the R&D volatility values, the chapter also uses data on public expenditures in different sectors that is reported by IFPRI's "Statistics on public expenditures for economic development (SPEED)" (IFPRI, 2015). The SPEED data is reported in billion PPP dollar (base 2005).

3.2 Methodology

Traditionally in economics, volatility has been measured by the second moment, i.e., the standard deviation or sometimes a higher moment (Ranciere et al., 2008) of the variable around its mean (Acemoglu et al., 2003;

[a] The correlation between the original public agricultural R&D expenditure series and the new public agricultural R&D expenditure (2005 PPP$) for each of the three datasets was above 0.97.

Raddatz, 2007). Volatility has also been quantified by other methods such as by measuring it as the coefficient of variation, i.e., the ratio of the standard deviation to the mean (Mobarak, 2005; Serven, 1999); as the standard deviation of the residual of an econometric regression (Lensink and Morrissey, 2006; Pritchett, 2000); and as the standard deviation of the cyclical component isolated by a statistical filter (Afonso and Furceri, 2010; Loayza and Hnatkovska, 2004). Although these techniques vary in the precise method used to calculate a reference value and measure average fluctuations around it, the different magnitudes of volatility estimated from these methods are found to be strongly correlated (Cariolle and Goujon, 2015).

We utilize a commonly used method in macroeconomic literature to estimate a *volatility coefficient*, calculating it as the standard deviation of the growth rate of the variable of interest (Cariolle and Goujon, 2015). In doing so we follow the method used by Stads and Beintema (2015) whose article is the only peer-reviewed study in the literature that undertakes a quantitative assessment of public agricultural R&D expenditure volatility for 30 Sub-Saharan African countries between 2000 and 2011.

Thus, for a variable "S," its logarithmic growth (G_t) is expressed as:

$$G_t = Ln\left(\frac{S_t}{S_{t-1}}\right) \tag{1}$$

where "S_t" denotes value of the variable in year "t" and "S_{t-1}" denotes its value in the preceding year ($t-1$).

The volatility coefficient (V) of the variable is calculated as the standard deviation of the yearly logarithmic growth:

$$V = \frac{1}{N}\sqrt{\sum_{t=1}^{N}(G_t-\mu)^2};\text{where } \mu = \frac{1}{N}\sum_{t=1}^{N}G_t \tag{2}$$

The formula in Eq. (2) is used to determine the volatility coefficient for the public agricultural R&D expenditure of each country. While a value of "0" for V indicates no volatility in the public agricultural R&D expenditures; higher values of V, indicate greater volatility in the expenditures. In what follows R&D volatility refers to volatility in public agricultural R&D expenditure.

4. Results: The extent and spread of public agricultural R&D volatility

4.1 Low-income countries have the most volatile R&D

The average global R&D volatility coefficient for 112 countries, across income groups, over 1981 to 2014, is found to be 0.19. Stads and Beintema (2015) categorize countries as having "low volatility" if their volatility coefficient (V) is between 0 and 0.1, "moderate volatility" if V is between 0.1 and 0.2, "high volatility" if V is greater than 0.2 and "very high volatility" if V is greater than 0.3. Although Stads and Beintema do not provide a specific rationale for these cut-off points, but the classification serves as a useful rule of thumb for a comparative assessment of the volatility coefficients. Thus, as per Stads and Beintema's metric the overall global level of volatility in agricultural R&D between 1981 and 2014 is moderate. However, a more disaggregated analysis is required to get a true sense of volatility.

Using the World Bank's income classification, we divide the countries in our sample into four income groups—low-income, lower-middle income, upper-middle income and high-income. Although our sample is not evenly split into each of the four country groups, but the number of countries in each group is close enough, ranging from 25 to 31. When we calculate the average volatility coefficient for each income group, we find low-income countries exhibit the highest amount of volatility in public agricultural R&D ($V=0.23$). In comparison, as Table 1 shows, volatility levels among the remaining three income groups are at comparable levels.

Table 1 Average levels of volatility in public agricultural R&D expenditure across income groups between 1981 and 2014.

Income group	Mean	N	Max	Min
Low-income	0.230	25	0.538	0.053
High-income	0.183	29	0.648	0.027
Upper-middle income	0.179	31	0.729	0.067
Lower-middle income	0.169	27	0.341	0.031
All	0.189	112	0.729	0.027

Source: Author's calculation. Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the annual public agricultural R&D expenditure series (billion PPP $ 2005) between 1981 and 2014.

Employing Stads and Beintema's classification, middle-income and high-income countries exhibit "moderate" volatility in public agricultural R&D expenditures, whereas low-income countries have "high" volatility.

4.2 There is considerable regional variation in R&D volatility

Table 2 reports the average R&D volatility for different regions. Because of data limitations, volatility could not be calculated for North America. Public agricultural R&D expenditure is the most volatile for the Sub-Saharan African region ($V=0.22$). This figure matches what Stads and Beintema (2015) find even though their analysis is for 2000–2011. Thus, the Sub-Saharan region can be classified as that of high R&D volatility.

R&D volatility in European and Central Asian region ($V=0.19$) is the second highest in the world and moderately volatile as per the Stads and Beintema classification. What is especially noteworthy is the level of R&D volatility in South Asia ($V=0.11$), the least in magnitude among all the regions being compared. In order to check whether regional volatility in public agricultural R&D for South Asia is disproportionately affected by India, because of the small sample size and because of India's large public agricultural R&D spending (Pardey et al., 2018), average regional volatility is re-estimated excluding India. Average regional volatility in public agricultural R&D excluding India is found to be only marginally higher ($V=0.12$). Thus, South Asia's relatively low levels of agricultural R&D volatility are not driven by India alone.

Table 2 Regional level average volatility in public agricultural R&D expenditure between 1981 and 2014.

Region	Mean	N	max	min
Sub-Saharan Africa	0.220	41	0.538	0.053
Europe & Central Asia	0.190	21	0.638	0.042
Middle East & North Africa	0.179	9	0.648	0.031
Latin America & Caribbean	0.168	27	0.729	0.067
East Asia & Pacific	0.164	9	0.448	0.027
South Asia	0.111	5	0.180	0.054
Total	0.189	112	0.729	0.027

Source: Author's calculation. Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the annual public agricultural R&D expenditure series (billion PPP $ 2005) between 1981 and 2014. Due to data limitations public agricultural R&D volatility could not be calculated for North America.

Similarly, given Brazil and China's high share of global public agricultural R&D expenditure (Pardey et al., 2018), the regional public agricultural R&D volatility for their respective regions is re-estimated without either of them. However, the average R&D volatility in the Latin American and Caribbean region and the East Asian and Pacific region, is at similar levels even in the absence of these two countries.

In Fig. 1 we map each individual country based on its R&D volatility using Stads and Beintema's classification. Darker hues on the map indicate countries with higher levels of volatility. "High" or "very high" R&D volatility can be seen in numerous countries in the African continent such as Zimbabwe, Tanzania, Eritrea, Sudan, Ethiopia, Niger, Mauritania, Gabon, Namibia, Sudan and Madagascar. Countries with high or very high R&D volatility are scattered across the remaining regions, for instance Venezuela and Paraguay (in South America); Laos (in East Asia) and Romania, Latvia, Estonia, Italy and Hungary (in Europe). The country with the most volatile public agricultural R&D is Venezuela ($V=0.73$). Given the economic challenges that Venezuela faced in the 1990s that have been compounded by the economic and political crisis of the subsequent decades (Doocy et al., 2019; John, 2019) this result is not unexpected. At the other end of the scale is Japan which has the least volatile public agricultural R&D expenditure ($V=0.027$). The stability of Japan's public agricultural R&D expenditures, combined with its long history of public agricultural research and extension (Hayami and Ruttan, 1970) and the fact that it continues to be among the top spenders in the world in terms of public agricultural R&D expenditures (Heisey and Fuglie, 2018; Pardey et al., 2018), suggests that agricultural R&D has been and continues to be a priority for Japanese policy-makers.

Juxtaposing the discussion of Section 2.1 with the country-level R&D volatility we find that the three new countries that have emerged as strong investors in agricultural R&D—Brazil, China and India—are also very stable in terms of their public agricultural R&D expenditures. As can be seen from Fig. 1, the volatility coefficient for each of these countries is less than 0.1, thereby, falling under the low volatility category of Stads and Beintema.

4.3 Globally volatility in R&D has declined over time but it has increased for high-income countries

In order to study changes in public agricultural R&D volatility through the decades, we re-calculate it for all the countries over three periods of time: 1981–1990, 1991–2000 and 2001–2010 (Fig. 2). Globally, R&D volatility

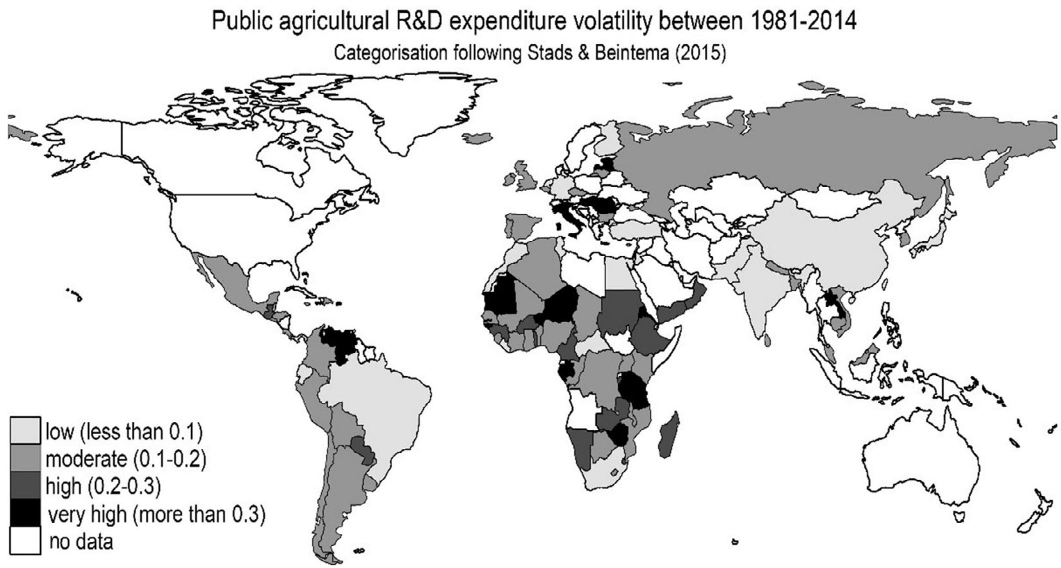
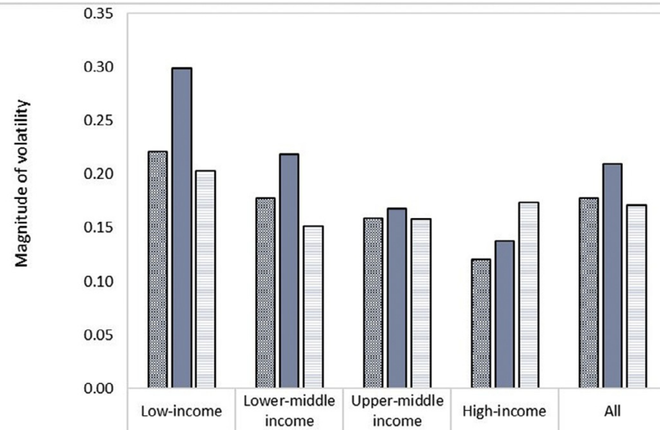


Fig. 1 Country-level R&D volatility classified as per Stads and Beintema (2015). *Source: Author's calculation. Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the annual public agricultural R&D expenditure series (billion PPP $ 2005) between 1981 and 2014.*



	Low-income	Lower-middle income	Upper-middle income	High-income	All
Public agricultural R&D expenditure volatility between 1981-1990	0.22	0.18	0.16	0.12	0.18
Public agricultural R&D expenditure volatility between 1991-2000	0.30	0.22	0.17	0.14	0.21
Public agricultural R&D expenditure volatility between 2001-2010	0.20	0.15	0.16	0.17	0.17

Fig. 2 Average volatility in public agricultural R&D expenditure over time by income group. *Source: Author's calculation. Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the annual public agricultural R&D expenditure series (billion PPP $ 2005) between the specified time period. The sample comprises of 112 countries.*

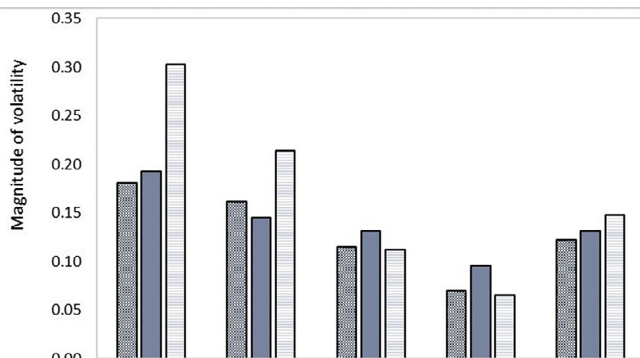
first increased in the 1990s and then decreased in the 2000s. Once we classify the countries by income group, we can see average R&D volatility in the 1990s was higher than in the 1980s for all the four income groups. Moreover the increase in volatility for low- and middle-income countries is much higher in comparison to the increases in volatility for upper-middle and high-income countries. The mid-1980s and 1990s were a period when structural adjustment programs (SAPs) were being implemented in many developing countries for macroeconomic stability, on the advice of and with the aid of multilateral organizations. The SAPs involved significant reductions of government support in various sectors, including agriculture (Yu et al., 2015). This makes it highly likely that the SAPs were a contributory factor behind the "high" and "moderate" volatility in public agricultural R&D expenditures in low- and middle-income countries during the 1990s.

The subsequent decade of the 2000s, however, shows some key changes, with volatility across all income groups falling under the "moderate" category. Another noteworthy development is that in the 2000s average R&D

volatility decreased for all but high-income countries. For high-income countries there is a distinct increase in R&D volatility over time. But despite this increase for high-income countries, in each of the three decades the highest average levels of R&D volatility are observed for low-income countries.

Based on these results, it is worth exploring whether the temporal changes in R&D volatility are also reflected in the volatility in total public expenditure during each of the three decades (Fig. 3). Using the SPEED dataset (IFPRI, 2015), we calculate the average volatility in total public expenditure in each of the three decades for each income group. Interestingly, volatility in total public expenditures is the highest for low-income and lower-middle income countries in the 2000s. On the other hand, average volatility in total public expenditures for the upper-middle and high-income country group increases in the 1990s and then declines in the 2000s. Thus, the volatility patterns of total public expenditures do not match those of agricultural R&D.

This suggests that perhaps a different set of considerations comes into play when governments take decisions related to public agricultural R&D expenditure as compared to when they make decisions about total public



	Low-income	Lower-middle income	Upper-middle income	High-income	All
Total public expenditure volatility between 1981-1989	0.18	0.16	0.11	0.07	0.12
Total public expenditure volatility between 1991-2000	0.19	0.15	0.13	0.10	0.13
Total public expenditure volatility between 2001-2010	0.30	0.21	0.11	0.07	0.15

Fig. 3 Volatility in total public expenditure over time by income group. *Source: Author's calculation. Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the total public expenditure series (billion PPP $ 2005) between the specified time period. The sample comprises of 142 countries.*

spending. In case of the latter, governments may have much lesser room to make changes given budget and resource constraints. In contrast public expenditure that is directed toward agricultural R&D also represents a trade-off with spending that could have been directed to other sectors. Thereby, contributing to volatility in case of public agricultural R&D spending. This fact is also reflected to some extent when the magnitudes of the average volatility in total public expenditure (Fig. 3) are compared to those for public agricultural R&D expenditure (Fig. 2).[b] In general, total public expenditure volatility is lesser than R&D volatility. The one exception to this is the low-income country group where the 2000s sees a huge spike in volatility of total public expenditure. It is possible that the global financial crisis of 2008–09, which triggered changes in the fiscal and monetary policy of many developing countries (Brumby and Verhoeven, 2010; Te Velde et al., 2008), contributed to this. However, a more disaggregated analysis would be required to unearth the reasons for this sharp increase in volatility in total public expenditures and for now we leave that as a topic for future research.

4.4 Across regions volatility in agricultural expenditure does not necessarily imply volatility in R&D

As a benchmarking exercise we compare the volatility in public agricultural expenditures (PAE) with the volatility in public agricultural R&D expenditures. We use the SPEED dataset (IFPRI, 2015), for public agricultural expenditure. The public agricultural expenditure statistics reported by SPEED notably do not include expenditure on R&D and multi-purpose development projects within their ambit. However, public expenditure on activities related to agriculture such as land conservation; flood control; irrigation; farm prices and income support; compensations, loans, subsidies and grants in connection with agricultural activities; and administration of agricultural affairs; is included (Yu et al., 2015). In order to minimize missing values, we compare volatility for the two categories of expenditures between 1990 and 2012. The regional volatilities in public agricultural expenditure and public agricultural R&D expenditure are presented in Table 3. Although the different sample sizes ($N=142$ for PAE) and ($N=116$ for public agricultural R&D) imply that volatility in the two categories of

[b] Although the differing sample sizes for the two expenditures makes the average volatility not strictly comparable, however, bearing this caveat in mind these values still have some insights to offer.

Table 3 Regional level volatility in public agricultural expenditure and public agricultural R&D expenditure between 1981 and 2014.

Region	Public agricultural expenditure volatility	Public agricultural R&D expenditure volatility
South Asia	0.42 (8)	0.13 (5)
Sub-Saharan Africa	0.39 (37)	0.27 (39)
Europe & Central Asia	0.32 (40)	0.29 (27)
Middle East & North Africa	0.31 (16)	0.21 (9)
Latin America & Caribbean	0.30 (23)	0.18 (27)
North America	0.27 (2)	NA
East Asia & Pacific	0.23 (16)	0.20 (9)
Total	0.33 (142)	0.24 (116)

Note: Volatility is calculated as the standard deviation of the yearly logarithmic growth of the respective series between 1990 and 2012. The figures in parenthesis denote the number of countries. Due to data limitations public agricultural R&D volatility could not be calculated for North America.

expenditure is not directly comparable, however, the within-category variation across regions offers interesting insights.

Table 3 reveals that the average volatility in public agricultural expenditures is highest in South Asia with a value of 0.42. The second highest PAE volatility is found in Sub-Saharan Africa with a value of 0.39. East-Asia and the Pacific region display the least amount of volatility in public agricultural expenditures.

Two points stand out in Table 3. The first is that South Asia has the highest average levels of public agricultural expenditure volatility but the lowest average levels of volatility in public agricultural R&D expenditure. While all other regions show a positive correlation between the PAE volatility and public agricultural R&D volatility, South Asia is the only region where the correlation between the two is negative (−0.28). This suggests that public expenditure in South Asia seems favorably disposed toward agricultural R&D, i.e., while governments in South Asia are not averse to altering public expenditure directed to the agriculture sector, this does not come at the cost of public agricultural R&D expenditure. The fact that over time countries in South Asia such as India have increased their share in global agricultural R&D (Pardey et al., 2018) further corroborates this claim. The relative stability of public agricultural R&D in South Asia may also be rooted in the legacy inherited from the Green Revolution of the 1960s–70s (Hazell, 2009).

The second point worth noting from Table 3 is the high correlation between volatility in public agricultural expenditure and volatility in public agricultural R&D that is seen for East Asia and the Pacific region (0.8). This region reflects the lowest levels of PAE volatility and also relatively low levels of volatility in public agricultural R&D. Thus, the region as a whole is very stable in the amount of public expenditure that is directed toward the agriculture sector and toward public agricultural R&D.

5. Discussion and implications

Drawing on the results from the previous section we flag five points for further discussion. The first point pertains to low-income countries. Volatility in public agricultural R&D expenditure continues to be the highest for low-income countries. However, a positive development in this regard is the fact that volatility in the latest decade for which data is available (2001 – 2010) is lower than it has ever been before. However, despite this declining trend, the average volatility for the low-income country group in the 2000s continues to be substantial ($V = 0.2$). With the COVID-19 pandemic of 2020, it is likely that volatility in public agricultural R&D would increase further as countries choose to re-allocate public expenditure away from activities not deemed to be "essential." Moreover, COVID-19 induced disruptions could further impact agricultural R&D projects (FAO, 2020). Thus, it is quite likely that the next decade may see an increase in public agricultural R&D volatility in low-income countries.

The second point relates to R&D volatility in high-income countries, which shows a distinct increase over time. This development combined with the fact that the growth of investment in public agricultural R&D has slowed down in high-income countries, has profound implications for these countries' own agricultural productivity growth as well as the global stock of scientific knowledge. According to Alston and Pardey (2014) the slowing growth in agricultural research spending by high-income countries has contributed to a slowdown in their agricultural productivity growth. Moreover, agricultural R&D activity in advanced economies in the past has generated positive spillovers in other countries, including economically comparable as well less-developed economies (Adetutu and Ajayi, 2020; Schiff and Wang, 2010; Schimmelpfennig and Thirtle, 1999). Such international research spillovers have in the past contributed to global agricultural productivity growth (Alston, 2002). Thus, a decrease in the growth of public agricultural expenditure and its instability in high-income countries is likely to impact the "size, shape and accessibility of the global stocks of scientific knowledge that underpin food and agricultural sectors worldwide" (Chai et al., 2019, p. 1).

Our third point follows from the previous one, in that the declining share of high-income countries in global agricultural R&D has been marked by a rise in the share of middle-income countries like China, Brazil and India (Pardey et al., 2016). In fact, China now spends more than the United States in both public and private agricultural R&D and if current trends are any indication is likely to continue to do so (Chai et al., 2019; Pardey et al., 2018). As highlighted in the results section, Brazil, China and India, also have considerably stable public agricultural R&D expenditures. Thus, these countries and in particular China, appear poised to play a key role in the realignment of the global geography of agricultural innovation in the future (Chai et al., 2019). But will they able to do so? Heisey and Fuglie (2018) argue that public agricultural research in these countries would be an imperfect substitute for the public agricultural R&D carried out in high-income countries. This is because of the important role played by universities in high-income countries in biological sciences, agricultural sciences and in the training of agricultural scientists, a role which has not yet been completely replicated in middle-income countries. They further argue that research in these countries has tended to focus on adapting technology to local environmental conditions, with limited evidence of cross-borders spillovers. Thus, if the global agricultural productivity frontier is to be advanced, these countries would need to focus on not just quantity and stability of public sector R&D, but also on its quality (Heisey and Fuglie, 2018).

The fourth point relates to the regional distribution of the level of public agricultural R&D and its stability. Sub-Saharan Africa has the lowest per capita agricultural R&D investment in the world (Pardey et al., 2016) which is also the most volatile. On the other hand, three of the top four countries in the world in terms of their public agricultural R&D expenditure—China, India and Japan—are from Asia. These countries also have very stable public agricultural R&D expenditures. This suggests that if current patterns of public agricultural R&D prevail, regional disparities in agricultural productivity are likely to exacerbate. Moreover, the geoclimatic specificity of agriculture (Alston, 2002) and institutional bottlenecks (Evenson, 2000; O'Gorman, 2015), may inhibit the absorption of foreign agricultural R&D innovation in the domestic context of Sub-Saharan Africa. Thus, it is imperative that Sub-Saharan Africa increase its public agricultural R&D spending and also ensure that it is stable. Since agricultural R&D in this region is largely public-funded, there is also room for complementing existing government spending with private sector agricultural R&D investment (Adetutu and Ajayi, 2020).

Given the considerable global volatility in public agricultural R&D expenditure as revealed in this chapter, we end this section with a final point on how best to address R&D volatility? Having in place a national R&D strategy that operates over a longer time horizon is one way to reduce R&D volatility at the national level. Another way would be to counter the "fragmented" decision-making around R&D. According to the fragmentation hypothesis, R&D resources are misallocated because of a fragmented research bureaucracy and uncoordinated decisions made by numerous sub-agencies (Oehmke, 1986). Thus, improving coordination between different sub-agencies along with according to each a meaningful degree of autonomy would help enhance the performance of national public agricultural R&D institutions. This would, in addition to increasing the incentives for policy-makers to invest in public agricultural R&D, also help in improving the information available to them as they undertake budgetary allocation decisions. Another way to tackle R&D volatility could be through appropriate international institutions. Such institutions can help reduce information and transaction costs and aid countries in leveraging on the international agricultural R&D spill-overs (Alston, 2002), so as to lower some of the domestic barriers toward investing in public sector agricultural R&D. Finally, by furthering our understanding of the political-economy factors influencing public agricultural R&D decisions, we may be better equipped to tackle R&D volatility. For instance, evidence of the incidence of research benefits, which is currently lacking (Alston, 2018), can be used to motivate policy-makers to direct investment toward public agricultural R&D.

6. Conclusion

Using a sample of 112 countries between 1981 and 2014 this chapter analyzed the extent and spread of volatility in public agricultural R&D expenditures. We found R&D volatility to be the highest in the Sub-Saharan African region and for low-income countries. But we also found that R&D volatility in low-income countries in the 2000s was the lowest it has ever been as compared to the preceding two decades. However, this value is still quite high. The co-existence of high R&D volatility with a disproportionately low share in global agricultural R&D in these countries (Pardey et al., 2016) is a matter of concern given the potential repercussions on agricultural productivity and food security.

On the other side of the coin are high-income countries that have shown a steady increase in R&D volatility since the 1980s. The global "retreat from public agricultural R&D" by high-income countries (Pardey et al., 2016, p. 303) in conjunction with the increasing volatility in their public agricultural R&D expenditures could have a detrimental impact on their agricultural productivity growth as well as the global stock of scientific knowledge related to agriculture. While the new top spenders of agricultural R&D—China, Brazil and India (Pardey et al., 2018) also have the most stable public agricultural R&D expenditures, it is unlikely that these middle-income countries will be able to substitute for the R&D activity undertaken in high-income countries. This is because these countries currently lack the institutional set-up and research orientation that enabled high-income countries to push the global agricultural production frontier outward (Heisey and Fuglie, 2018). Thus, the quantity, stability as well as quality of public agricultural R&D activity in these countries will play a key role in shaping agricultural innovation in the future.

Given the fact that agriculture is a sector that has direct and profound implications for a range of the United Nations' Sustainable Development Goals (SDG), agricultural research is a prime candidate for embodying wider research impact (Weißhuhn et al., 2018). It can play an important role in boosting agricultural productivity, improving food security and environmental sustainability and in combatting climate change. This makes increased and stable investment in public agricultural R&D, an important developmental priority.

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