The Effects of Plant Breeders' Rights on Wheat Productivity and Varietal Improvement in South African Agriculture

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Abstract: The strengthening of the intellectual property rights (IPRs) for plant varieties provide incentives for breeding companies to invest more resources in plant breeding. The main objective of this paper was to analyze the effects of strengthening the wheat variety intellectual protection on wheat productivity and the release of new varieties. The strength of IPR systems was measured using an intellectual property (IP) protection index, and plant breeders' rights (PBRs) granted for wheat varieties. The empirical analyses were based on correlation and multiple regression analyses. The results showed that strengthening IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios. There is a need for more incentives beyond granting PBRs and strengthening of IPR systems to be provided in the whole wheat sector to stimulate increased investments and the release of new varieties.

1. Introduction

The global demand for food increases with the growing world population, projected to be 9.8 billion in 2050 and 11.2 billion by 2100 [1]. The challenges of an increasing world population, global climate change, shortages of irrigation water and degradation of agricultural land increases the need to enhance agricultural productivity. Limited opportunities for opening new agricultural land means that increasing productivity from existing cropping systems and promoting sustainable production remains an important alternative to meet the rising demand for food and fiber [2–4]. Research in varietal innovations, particularly for main food crops such as wheat, remains important for increasing agricultural productivity and addressing food security concerns, as well as meeting the growing world food demand.

The developments and changes in intellectual property rights (IPRs) systems for agricultural innovations (such as varietal improvements) are one of the institutional factors expected to impact on the productivity of agricultural systems (other factors that affect agricultural productivity include capital, land, labor, environmental and climatic factors and technological capabilities) [5]. The International Union for the Protection of New Varieties of Plants (UPOV), established in 1961, advocates for the strengthening and harmonization of plant variety protection (PVP) laws and standards. The strengthening of *sui generis* plant IPRs is expected to provide incentives to stimulate investments in plant R&D as development of the local seed sector [6]. In addition to this, stronger IPRs are expected to

stimulate technology development and transfer and generate effective utilization of genetic resources that would contribute to enhancing agricultural productivity and economic benefits [5].

Despite the aforementioned arguments for stronger plant IPRs, empirical research on their effects on agricultural innovations and productivity have produced mixed results. For example, Campi [5] found significant and positive relationships between stronger IPRs and cereal productivity in high- and low-income countries, while the relationship was negative and insignificant in middle-income countries. In a separate study, Naseem et al. [7] found that plant variety protection (PVP) contributed to the development of more varieties and positively impacted cotton yields in the United States. On the negative side, plant IPRs have been argued to affect innovations and availability of new plant varieties, increasing input market concentration and with an impact on productivity that is either insignificant or negative [8].

In addition to this, some empirical studies have argued that IPRs or PVP systems might not be strong enough to stimulate significant investments in plant breeding research and innovations [6,9,10]. For example, Tripp et al. [6], based on case studies from China, Colombia, India, Kenya and Uganda, found that development of PVP systems in developing countries were inadequate for stimulating the development of the local commercial seed sector, and recommended that efforts need to be integrated into broader seed system development strategies. Furthermore, the monopoly power provided through IPRs has been argued to negatively affect domestic innovation, technology transfer, local market development and agricultural productivity [11].

However, there is no empirical analysis that has been done specifically for the South African wheat sector to explore the relationship between plant breeders' rights and/or the strengthening of the IPRs environment for plants with wheat productivity. Additionally, there is no empirical work that has assessed how strengthening wheat variety IPRs has affected the wheat sector variety improvement landscape and seed industry. The empirical analyses from this research paper contributes to the knowledge and debate on the effects of plant breeders' rights and/or the strengthening of IPRs on plant varieties on agricultural productivity, and the release of improved varieties and changing roles of public and private sector R&D investments in agriculture. Therefore, the main objective of this paper was to analyze the effects of strengthening wheat variety intellectual protection on wheat productivity and varietal improvement (the release of new improved varieties). Stronger intellectual property rights are expected to stimulate investments in wheat productivity and varietal improvements. The strength of IPRs systems was measured using an intellectual property (IP) protection index, plant variety protection legislation and the number of plant breeders' rights granted for wheat varieties.

The rest of the paper is organized as follows: Section 2 discusses the review of literature on the effects of IPRs on agricultural development. Based on the reviews, hypotheses are proposed for the current study. The methodology and data of the study are presented in Section 3. Section 4 presents and discusses the empirical estimation results. The conclusions and recommendations are presented in Section 5.

2. Literature Review

Review of Empirical Studies on the Relationship between IPRs and Agricultural Innovations and Productivity

Plant breeders' rights (PBRs) are a form of intellectual property rights (IPRs) that provide exclusive rights to the breeder so they can benefit from their innovations. This means the breeder has protection from unauthorized imitation of the protected variety for commercial purposes by competitors and farmers. Furthermore, investments in agricultural innovations such as varietal improvements are motivated by objectives of acquiring and growing market share by breeders [12]. For example, the main factors that contribute to the growth in private agricultural R&D investments include increased demand for modern agricultural inputs driven by increased demand for food and fiber, incentives stimulated by policy reforms that deregulated agricultural input sectors and the strengthening of IPRs that help protect innovations from being imitated without permission [13–15]. Overall, the strengthening of

the IPRs for plant varieties is expected to provide incentives for breeding companies to invest more resources in plant breeding. The strengthening of IPRs for plants is expected to result in an increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth [5,6].

Despite the incentives presented for promoting IPRs for plants, the development of new plant innovations requires access to existing genetic material. The restrictions on access to existing genetic material presented by IPRs in plant varieties may affect breeding programs, although there may be legislative exceptions that provide access to such material for R&D purposes [5]. The protection from the IPRs can lead to high concentration and creation of monopolistic actors in seed input markets that adversely impact local innovations, market development and productivity [8,11]. On the contrary, Wright and Pardey [16] argue that since the diffusion of IPRs across the world, developments in scientific innovations (rather than IPRs) have contributed to yield improvements.

The impact pathway of the effects of IPRs on productivity is indirectly observed and may be difficult to isolate. Most of the research on effects of IPRs focus on their impacts on agricultural innovations, and there is limited empirical evidence on the relationship between IPRs and productivity [5]. This means research on the effects of IPRs on wheat productivity provides an important contribution to empirical knowledge in this field. Empirical research on the relationship between IPRs, varietal innovations, agricultural productivity, trade and economic growth have produced mixed results. Some of the empirical findings are briefly discussed below. Using a panel of countries and data from the years 1961 to 2011, Campi [5] assessed the effects of strengthening intellectual property (IP) protection on agricultural productivity. The effect of strengthening IP rights (IPRs) on both wheat and maize was explored using an index of IP protection for plant varieties. Empirical results found that for middle-income countries such as South Africa, the relationship between stronger IPRs and cereal productivity (wheat and maize) was insignificant. This was contrary to the same relationship in high- and low-income countries. The implications for these results is that variety IP protection may not have positively impacted on commercial wheat productivity in South Africa.

Spielman and Ma [17] applied an Arellano–Bond linear dynamic panel data estimation approach using a data set of six major crops to assess the effect of IPRs on yield growth through stimulating incentives for investments by the private sector in varietal improvements. The findings from the study showed that despite the effects being crop-specific, different forms of IPRs (biological and legal) contributed to the reduction of the gap in yields between developing and developed countries. In a separate study, Payumo et al. [18] analyzed the effect of strengthening IPRs systems in Trade-Related Aspects of Intellectual Property Rights (TRIPS) member countries on agricultural gross domestic product (GDP) for the period of 1980–2005. The two variables were found to be positively related in both developed and developing countries.

Pray and Nagarajan [19] found that in India, strengthened IPRs allowing innovators to patent their innovation positively impacted on private agricultural research. Flister and Galushko [20] argue that introduction of the PVP Law in Brazil stimulated private investments in wheat R&D and the establishment of a strong private wheat breeding sector. These results indicate that strengthening IPRs systems would contribute to stimulating private sector investments in agricultural R&D.

Kolady and Lesser [21] analyzed the impacts of the implementation of PVP to crop productivity in Washington State of the United States. The findings from this study showed that PVPs had a positive relationship with private investments in open pollinated crops (such as wheat). Additionally, implementation of PVPs resulted in an increased number of high yielding varieties of these crops that were released from both private and public breeding programs. The authors extended the implications from their analysis as important lessons for developing countries on how IPRs for plants and their Trade-Related Aspects of Intellectual Property Rights (TRIPS) commitments can affect both the release of high yielding varieties and private sector investments.

Naseem et al. [7] examined the effects of PVP and cotton yields in the United States. The empirical findings found that PVP contributed to the development of more cotton varieties and had a positive

impact on yields. The results contrasted the criticism that PVP was more than a marketing tool with insignificant impacts on agricultural productivity.

Knudson and Pray [22] analyzed the impacts of the Plant Variety Protection Act of 1970 (PVPA) on public sector research priorities of five crops (corn, wheat, sorghum, cotton and soybeans) in the United States. The empirical regression results showed social benefits from public research investments were important in directing research priorities. Furthermore, the results showed some support that new income opportunities provided by the PVPA influenced the direction of public research. Similarly, for the current research, the expectation was that granting of PBRs and a stronger IPRs environment would stimulate further investments in wheat varietal improvements and the release of improved varieties that would contribute to improved productivity.

Tripp et al. [6] examined the effects of PVP systems in five developing countries (China, Colombia, India, Kenya and Uganda). The findings from the study showed that PVP systems were inadequate for stimulating development of commercial seed development. The authors argued that to be effective, PVP systems should be framed within broader seed system development strategies. Léger [23] investigated the role IPRs in the Mexican maize breeding industry. The empirical results indicated that IPRs had no role in the industry and did not stimulate innovation as expected. The author argued for revision of the IPRs theory to integrate country characteristics such as quality of the institutional environment and role of transaction all important for well-functioning IPR systems. Considering these factors is expected to result in IPRs systems contributing even a small role in developing countries.

Dosi et al. [24] analyzed the relations between appropriability, opportunities and rates of innovation. The evidence from the study suggested that IPRs were not a very important mechanism for breeding firms to earn profits from their innovation. Based on the findings, the authors highlighted that, at best, IPRs have no impact, or could have negative impacts on rates of innovation. The authors argued that each technology paradigm was more important in determining technology- and industry-specific patterns of innovation.

Alston and Venner [25] analyzed the effects of the PVP Act (PVPA) of 1970 in the United States on the wheat genetic improvement. The PVPA was expected to strengthen IP protection for plant breeders, stimulate investments in varietal R&D and improve varietal quality and enhance royalties. The empirical results found that the PVPA contributed to increased public investments (and not private sector investments) in wheat varietal improvement. The results on the impacts of the PVPA on experimental and commercial wheat yields was negative. The authors found that the PVPA did not have much impact on excludability in wheat varieties.

Campi and Duenas [11] explored the effects of IPRs on agricultural trade for the period of 1995 to 2011 using an IPRs index for 60 countries since the signing of the TRIPS agreement. Various econometric methods were used on panel data of the 60 countries, comprising 28 developed countries and 32 developing countries. The results showed that strengthening IPRs does not have a clear cut relationship with an increase in trade volumes. The authors found a negative relationship between stronger IPRs and trade volumes for imports and exports of agricultural products. In addition, the estimated gravity model predicted negative effects of IP protection on total bilateral trade for both importers and exporters in developing countries. Strengthening IPRs systems in exporting countries had a negative effect on the probability of creating new trade partners in developing countries. On the other hand, strengthening IPRs protection in importing countries had a positive effect on the probability of finding new trade partners for the samples that included developing countries. Overall, the authors found that strengthening IPRs has a negative effect on agricultural trade since the signing of the TRIPS agreement, mainly in developing countries

Zhou and Sheldon [26] analysed the relevance of trade of agricultural seeds and its sensitivity to the levels of intellectual property rights of a country. The authors further investigated the role of IPRs in terms of seed transfer through trade, asking the questions of whether IPRs promote access to seeds or not. The IPRs variables were included in the modified gravity model as trade distortions on seed trade between the U.S. and other countries. Specifically, relevant international agreements

on IPRs (UPOV and World Trade Organisation (WTO)) were considered as membership dummies. The results showed that the U.S. WTO-TRIPS membership has a significant positive impact on seed exports, suggesting that seed trade is positively affected by implementation of the TRIPS agreement.

Sweet and Eterivic [27] examined the effects of patent rights (intellectual property rights systems) on total factor productivity. The authors applied a dynamic panel regression for 70 countries for the period 1965 to 2009. The results showed that stronger patents rights were insignificant for agricultural productivity growth in developing and industrialized countries. Over the period of analysis, the results showed that growth in productivity cannot be attributed to patent rights. The authors argued that patent rights were not a good proxy for technological progress as they can only cover patentable innovation. The authors also found that patent rights were irrelevant to productivity. From this study, improving and upgrading productivity does not depend on the organization of private rights or the extension of their monopoly power.

Gold et al [28]. examined the questionable issue on the positive impact of IPRs on economic growth in developed and developing countries. In the study, an index was used to assess the strength of IP protection in 124 countries for the period 1995 to 2011. They also examined the relationship between IP protection and GDP per capita in detail. The results show that the assumptions that higher levels of IP protection lead to increased economic growth is misleading and conflicting. Much of the problem arises from the way IP protection is measured through laws and formal IP, while not measuring the actual IP practiced in the countries. The authors found that increased levels of formal IP protections lead to economic growth in lower-middle-income countries through the encouragement of high levels of IP-rich imports and the boosting of domestic levels of innovative activities. For higher lower-middle-income countries, higher levels of IP protection encouraged IP-rich imports but not domestic innovation. Finally, on the relationship between IP protection and GDP per capita, political influence was found to be much stronger than economic influence.

In line with all the literature highlighted above, all studies showed the different relationships of IPR systems on innovation, productivity and yields. Many authors found mixed results in these relationships. This study aims to show the relationship and status of intellectual property rights systems in South Africa. South Africa and Kenya are the only countries in Africa who are members of UPOV. South Africa has a well-established PBR system that has not been thoroughly analyzed. This study seeks to further analyze the relationship of IPRs systems on productivity and varietal release in South Africa, focusing on the wheat breeding program. This brings the African status of IPRs systems to the body of knowledge.

Based on this review of literature and findings presented above, we expect the strengthened PBRs and IPRs environment to have positive effects on varietal improvements and productivity in South Africa and proposed the following hypotheses:

Hypothesis 1 (H$_1$). *Strengthening plant breeders' rights in South Africa increased investments and the release of improved wheat varieties.*

Hypothesis 2 (H$_2$). *Strengthening plant breeders' rights in South Africa positively and significantly impacted wheat productivity.*

The discussion above indicates that the empirical research on the effects of IPRs for plants on varietal innovations and crop productivity are mixed. Some of the contributing factors to the mixed findings may include country specific characteristics (such as institutional environment), the technologies being considered and imperfect data. Campi [5] argues that IPRs systems may be the result and not the cause of innovation and improvements in productivity. There is need for further empirical research to explore the relationship between IPRs systems in different country contexts and sectors. The current study contributes to the growing knowledge in the field of IPRs systems through analyzing the effects of plant breeders' rights in the South African wheat sector on the release

of new high yielding varieties and wheat productivity. The proposed hypotheses above are empirically tested below.

3. Materials and Methods

Research Methodology

The methodology used to analyze the relationships between plant breeders' rights and wheat commercial yields and productivity in South Africa is presented in this section. To measure the productivity of wheat, the study used yields calculated as total commercial wheat output divided by total harvested area in hectares. Campi [5] discusses the advantages of using yield as a measure of productivity over other indicators, such as output per worker, or total factor productivity, such as reliability of yield data, and its reflection to a large extent on the effect of technical change in agriculture. The dependent variables were the log of wheat yields and the number of wheat varieties released each year. The independent variables included data on plant breeders rights for wheat compiled as part of this research [29], and the IPR Index developed by Campi and Nuvolari [30].

The IPR Index quantifies the strength of IP protection for plant varieties in different countries (who are members of the UPOV convention) for the period of 1961 to 2011. The IPR index has five equally weighted elements (ratification of UPOV Conventions, farmers' exception, breeder's exception, protection length and patent scope) that measure the strength of the IP protection system for plant varieties in each country [30]. South Africa is a member of the UPOV convention and the respective data for the country was used for empirical analyses to explore the relationship between stronger IPRs and wheat productivity and wheat varietal research improvements in the country. Detailed discussion of the evolution of plant breeders' rights in wheat varietal improvement in South Africa is presented by Nhemachena et al. [29]. The period from 1996 in which South Africa became amended the PBR Act (Act 15 of 1976) to confirm with the constitution and the UPOV 1991 was also included as a dummy independent variable. This represented an undertaking to implement stronger IP protection for innovations from the country.

Similar to other studies [5,18,25,31] that have explored the relationship between IPRs systems and agricultural productivity, the empirical analyses of the effects of IPRs systems and wheat varietal release and productivity in South Africa was based on correlation analysis and multiple regression analysis. Correlation analysis was used to explore the nature of the relationships between IPRs systems and wheat productivity as well as release of new varieties both by the Agricultural Research Council-Small Grains Institute (ARC-SGI) wheat breeding programme and Sensako (the main domestic private sector actor). To explore the hypothesized relationships above, simple regression models were defined as in Equations (1) and (2) below:

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \tag{1}$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \tag{2}$$

where Y_t is the logarithm of wheat yields in year t, V_t is the number of wheat varieties released in each year, IPR_t is the index of IPRs protection in year t and μ_t is the error term.

To further explore the relationships between IPRs systems, plant breeders' rights and wheat productivity and the release of new wheat varieties, the study applied multiple regression analyses defined by the following Equations (3) and (4) below. In this case, PBRs granted to both the ARC-SGI and Sensako, representing the domestic private companies (DP), were added as independent variables. The total number of wheat PBRs granted each year was also used as an independent variable in place of the total individual variables of PBRs granted to the ARC-SGI and Sensako.

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{DP_t} + \alpha_5 PBRAct_t + \mu_t \tag{3}$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{DP_t} + \alpha_5 PBRAct_t + \mu_t \tag{4}$$

where PBR_{ARC_t} and PBR_{DP_t} are the number of PBRs granted for wheat variables released by the ARC-SGI wheat breeding programme and Sensako respectively, $PBRAct_t$ is the years after which South Africa amended the PBR Act (Act 15 of 1976) to confirm with the constitution and the UPOV 1991. The relationship between both wheat yield and number of varieties released each year was tested using the following multiple regression equation with PBRs granted to both the ARC-SGI and Sensako added as independent variables. The total number of wheat PBRs granted each year was also used as an independent variable in place of the individual variables of PBRs granted to the ARC-SGI and Sensako. Table 1 below summarizes the variables used in the regression analyses and the data sources. The empirical results and discussion are presented in the next section.

Table 1. Variables used in the regression analyses and data sources [1].

Variable Name	Description	Data Source
logyield	Wheat yield (tonnes/ha)	Campi [5]
Intellectual property rights (IPRs)	Index of IPRs protection for plant varieties	Campi and Nuvolari [30]
PBRAct$_t$	Dummy variable for the period the PBRs (plant breeders' rights) Act was amended	Nhemachena et al. [29]
PBR$_{ARC}$	Number of PBRs granted for wheat varieties released by the ARC-SGI (main public sector actor)	Nhemachena et al. [29] (The original source was 'The South Africa Plant Variety Journal that was established in 1978)
PBR$_{DP}$	Number of PBRs granted for wheat varieties released by Sensako (main domestic private sector actor)	Nhemachena et al. [29] (The original source was 'The South Africa Plant Variety Journal that was established in 1978)

[1] Data used in the cross-country study: "CAMPI, M. 2017. The effect of intellectual property rights on agricultural productivity. Agricultural Economics, 48, 327–339" was provided by Dr Campi.

4. Results and Discussion

4.1. Wheat Varietal Improvement and Changing Structure of Seed Market in South Africa

This section briefly discusses the changing roles in wheat varietal improvement in South Africa based on shares of varieties in the national commercial crop. The analysis of shares of wheat seed market were based on the shares of varieties in the national crop obtained from the South African Grains Laboratory (SAGL) and former Wheat Board reports [32]. Details of these data are elaborated. Figure 1 presents the summary of breeders' shares of wheat varieties based on area estimates from cultivar composition in national output. The analysis shows varying trends in the proportion of wheat seeds obtained from breeding programs from the main wheat breeding programs in the country: ARC-SGI (main public wheat breeding programme), Sensako (main private wheat breeding programme) and Pannar (minor private wheat breeding programme).

The graph indicates that from the period of 1992 when the ARC was established and prior when the Wheat Board was still operational, the results show that public research support for wheat breeding played a significant role in producing wheat varieties that contributed to the national crop. For the period up to the deregulation of the wheat sector, the wheat national crop was dominated by publicly developed varieties. These trends rapidly changed after deregulation with the private sector, with Sensako mainly dominating the wheat input market.

The deregulation of the wheat sector with the abolishment of the Wheat Board in 1996 also resulted in the structural transformation of the wheat seed sector market. This led to the reduction of the share of the market share of public-produced wheat varieties in the national crop decreasing from above 50% in 1997 to less than 2% in 2015 while that of the private sector (particularly Sensako) rapidly increased

from 37% to 96% in the same period. Experiences in India also show structural transformation of agricultural input industries after policy reforms that liberalized input sectors [19].
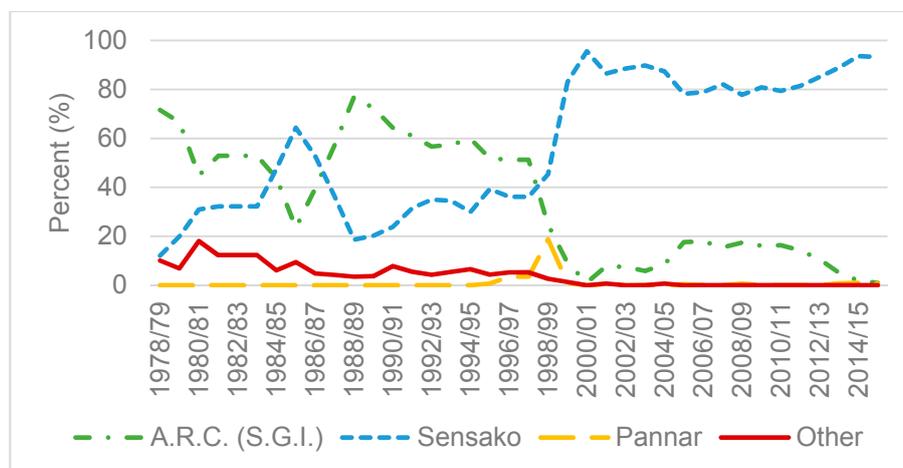

Figure 1. Summary of breeders' shares of wheat varieties based on area planted estimates from wheat cultivar composition in national crop; Source: Nhemachena et al., 2019.

Furthermore, the results clearly show that the domestic private sector has dominated the wheat seed sector, and this was rapid since the deregulation of the wheat sector in 1996. The findings conform to the review evidence from Pray and Fuglie [13] that the role of the private sector in developing improved agricultural and food technologies has increased in the recent decades and private agricultural R&D investments have surpassed that of the public sector. Based on Pray and Fuglie's assessment, new commercial opportunities created by scientific advances and the liberalization of agricultural input markets have been the major factors driving the growth of private agricultural R&D investments. The authors argued that based on empirical evidence from many studies, there are complementarities between public and private agricultural R&D despite the increased role of private R&D.

Similarly this study argues that the ARC-SGI and the domestic private sector can provide complementary benefits to each other. In this case, public wheat varietal improvement R&D investments can stimulate additional domestic private sector R&D investments and vice versa. However, when public and private R&D investments substitute each other, the private sector tends to reduce their R&D investments compared with what they could have invested in the absence of public R&D [13]. Additional research would be required to test the complementarity versus substitution effects in public and private wheat varietal improvement research which could not be done in the current study.

From the analysis above, it can also be argued that deregulation has contributed to a concentration of wheat seed markets into a single private actor—Sensako—which acts as a monopoly. Intellectual property rights, through providing temporary monopoly in the use of an innovation, impose social costs as the monopolistic firms sell less at higher prices, and may also innovate less, taking advantage of their market power [33]. The creation of monopolistic firms in both genetic resources and seed markets have adverse implications on the efforts to enhance agricultural productivity. For strategic and main food crops in a country, it may be of national interest to ensure public resources are invested in plant breeding and varietal improvement. However, this could not be done in the current research., and it is up to future research to explore whether Monsanto is acting like a monopolist, raising wheat seed prices and lowering seed supplies.

4.2. Correlation Analyses of Wheat Productivity, Number of Varieties Released and IPRs

The empirical analysis of the relationship between strong IPRs and plant breeders' rights, and wheat productivity and release of new high yielding wheat varieties are presented and discussed in this

section. The correlation analysis of the relationship between the wheat productivity and the variables explaining IPRs and PBRs are presented in Table 2 below. The correlation analysis was also performed for the relationship between the number of wheat varieties released and the variables explaining IPRs and PBRs (Table 3).

The correlation results indicate that all coefficients of the relationships between the dependent variables (wheat productivity and number of wheat varieties released) are positive and statistically significant at 5% and 1% significance levels. The findings from this study contrast finding by Campi [5] who found no significant relationship between IPRs systems and cereal productivity in middle-income countries such as South Africa. The findings show that wheat productivity and the number of wheat varieties released correlate with each of the variables representing strengthening of IPRs.

Table 2. Correlation analysis between wheat productivity and IPRs.

| | **Descriptive Statistics and Pearson Correlations** | | | | | | | |
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Wheat productivity	9.49	0.54	1.00					
2. IPRs	1.81	1.11	0.93 ***	1.00				
3. PBR$_{Actt}$	0.33	0.48	0.80 ***	0.84 ***	1.00			
4. PRB granted	1.71	2.92	0.59 ***	0.62 ***	0.63 ***	1.00		
5. PBR$_{ARC}$	0.41	1.02	0.38 ***	0.36 ***	0.37 ***	0.16	1.00	
6. PBR$_{DP}$	1.82	2.78	0.63 ***	0.60 ***	0.60 ***	0.35 **	0.38 ***	1.00

Notes: M = Variable mean, SD = standard deviation, *** = $p < 0.01$, ** = $p < 0.05$.

Table 3. Correlation analysis between number of wheat varieties released and IPRs.

| | **Descriptive Statistics and Pearson Correlations** | | | | | | | |
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Number of wheat varieties	3.71	2.74	1.00					
2. IPRs	1.81	1.11	0.50 ***	1.00				
3. PBRAct$_t$	0.33	0.48	0.37 ***	0.84 ***	1.00			
4. PRB granted	1.71	2.92	0.41 ***	0.62 ***	0.63 ***	1.00		
5. PBR$_{ARC}$	0.41	1.02	0.32 **	0.36 ***	0.37 ***	0.16	1.00	
6. PBR$_{DP}$	1.82	2.78	0.32 **	0.60 ***	0.60 ***	0.35 **	0.38 ***	1.00

Notes: M = Variable mean, SD = standard deviation, *** = $p < 0.01$, ** = $p < 0.05$.

Using rough, commonly-held guidelines on the sizes of correlations, analysis of the correlation sizes between wheat productivity and the PBRs granted (total and Sensako) show correlations ranging from 0.5 to 0.8 which indicate that there is a large correlation and good evidence of association between these variables. The results for the PBRs granted to the ARC-SGI and wheat productivity have a correlation of 0.38, which points to moderate evidence of association between the variables. Furthermore, the correlations between wheat productivity and the IPR Index and the period after amendment of the PBR Act to align with the constitution and UPOV 1991 have a high correlation and strong evidence of association (above 0.80) between the variables. The results point to more influence of Sensako (domestic private sector) developed varieties in the harvested national crop. The findings also point to the stimulation of the private sector investments by stronger IPRs systems in the country. As indicated in the review above, evidence from other countries such as India and Brazil demonstrate that private sector investments were stimulated by strengthened IPRs systems [19,20].

Additionally, the correlations between the number of varieties released and PBRs granted (total, ARC-SGI and Sensako) were found to be statistically significant (at 5% and 1% levels). Using the rule of thumb for correlation analysis the results [34] of the coefficients were in the range 0.30 to 0.49, which indicate moderate correlations and/or evidence of association between the variables. From these results it can be argued that although there is some relationship between the number of varieties released and PBRs granted, the relationships are not very strong. This might point to the fact that PBRs alone do not have a very strong influence on the decisions made to invest more in wheat varietal improvements. For example, for private firms, the seed royalties are insufficient in conducting

basin research and experiences in Brazil, indicating that the private sector directed their investments to more profitable ventures like applied research and the development of new cultivars [20]. This means stimulating investments in wheat varietal improvements in South Africa should go beyond strengthening IPRs systems.

Although the results suggest the dominance of private sector activity in wheat breeding in the country, empirical evidence from other countries indicate that public research investments provide complementary stimuli to investments by the private sector in agricultural R&D [34]. For example, in India, public research institutions generated parental breeding lines that were used by private seed companies to produce hybrid varieties for crops such as cotton, sorghum, maize and rice [19]. Pedigree analysis of the domestic private sector varieties especially from Sensako [32] also demonstrated that they have benefited from parental breeding lines produced by the ARC-SGI. This indicates that complementary investments in wheat varietal improvements should be strengthened as part of efforts to improve the delivery of improved wheat varieties and enhance productivity in the country.

4.3. Estimating Effects of IPRs and PBRs on Wheat Productivity and the Number of Varieties Released

To further explore the findings from correlation analyses presented above, regression analyses were performed. As indicated above, the dependent variables used in the analyses were wheat productivity and the number of wheat varieties released. The independent variables included the IPRs index, number of plant breeders' rights granted for wheat varietal releases, plant breeders' rights for ARC and Sensako varieties and a dummy variable for the period the country amended the Plant Breeders' Rights Act to confirm with the constitution and UPOV 1991. Econometric tests were performed to test for potential multicollinearity in independent variables before performing the final regressions. If multicollinearity exists among the regressors, it results in imprecise estimates of the parameters [34].

Furthermore, multicollinearity was tested based on the variance inflation factor (VIF) The correlation analyses presented above did not show very high correlations to suspect problems of The VIF values of less than 10 in the regression results imply that multicollinearity is not a problem in the model specification. The empirical results from the estimations (as indicated by low values of VIF which were less than 10) showed that multicollinearity was not a major issue in each of the models. However, as indicated above, multicollinearity was a challenge with other variables used by [11] and these were dropped in the regressions performed for this study.

Another challenge of multiple regression analyses is the presence of heteroscedasticity in the error terms, which results in inconsistent but inefficient estimates of parameters and inconsistent estimates of the covariance matrix [34]. Incorrect inferences can be drawn if hypotheses are tested in the presence of heteroscedasticity. The Breusch–Pagan/Cook–Weisberg test was performed to test for heteroscedasticity. The probabilities of the chi-square tests were above the 0.10 significance level for all the models indicating heteroscedasticity, which was not a major issue in the estimated models (Tables 4–7). Despite the test results indicating that heteroscedasticity was not a major issue, the regression models were estimated using a heteroscedasticity-robust standard error estimation procedure. The heteroscedasticity-robust standard error estimation computes robust variance estimators using equation level scores and a covariance matrix [35].

We also tested for auto-correlation using the Durbin–Watson (DW) d statistic [36]. The post-estimation test for auto-correlation revealed problems of auto-correlation in some of the estimated models (DW statistic (original) in Tables 4–7). To address the problem of auto-correlation, we estimated the models using the STATA Prais–Winsten and Cochrane–Orcutt regression procedure. The results of the transformed regressions and Durbin–Watson *d* statistic are presented at the right-hand side of Tables 4–7. The transformed Durbin–Watson *d* statistic in Tables 4–7 is about 2 for all models indicating no further challenge of auto-correlation. Also, the regressions were estimated using a heteroscedasticity-robust standard error estimation procedure as explained above.

The results of a simple regression model of each of the dependent variables and IPRs index and number of PBRs granted are presented in Tables 4 and 5, respectively. The R-square adjusted of the models with IPR Index as an independent variable show that the regressions explained 70% and 25% of the variability in wheat productivity and the number of wheat varieties released, respectively. For the regressions with the PBRs granted as independent variable the models explained 33% and 0.4% of the variability in the same dependent variables, respectively. The coefficients of the IPR Index and PBRs granted show that both independent variables had a positive and statistically significant relationship with both wheat productivity and the number of wheat varieties released. These results confirm the findings of the correlation analyses discussed above and demonstrate that strengthening IPRs systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. This confirms the findings discussed in the literature review above from other parts of the world [7,17,21,22] that strengthening IPRs systems stimulates investments in plant breeding, the release of new varieties and enhances crop yields.

Table 4. Simple regression model of wheat yield/number of varieties released and IPR Index.

	Ordinary Least Squares (OLS) Parameters			Cochrane-Orcutt AR (1) Parameters	
Dependent Variable: Wheat Productivity					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	8.66 ***	0.000	0.00	8.68 ***	0.000
IPR Index	0.46 ***	0.000	1.00	0.45 ***	0.000
R-square	0.86			0.70	
Chi-square (hettest)	1.37	0.2422			
Durbin–Watson (DW) statistic (original)	1.1116			1.1116	
DW statistic (transformed)				1.7920	
Dependent Variable: Number of Wheat Varieties Released					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	1.52 ***	0.000	0.00	1.52 ***	0.004
IPR Index	1.27 ***	0.000	1.00	1.23 ***	0.000
R-square	0.25			0.25	
Chi-square (hettest)	0.47	0.4952			
DW statistic (original)	2.0574			2.0574	
DW statistic (transformed)				1.9985	

Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = $p < 0.01$.

Table 5. Simple regression model of wheat yield/number of varieties released and PBRs granted.

	OLS Parameters			Cochrane-Orcutt AR (1) Parameters	
Dependent Variable: Wheat Productivity					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	9.30 ***	0.000	0.00	9.93 ***	0.561
PBRs granted	0.11 ***	0.000	1.00	0.004 ***	0.000
R-square	0.35			0.004	
Chi-square (hettest)	0.98	0.3233			
DW statistic (original)	1.1458			1.1458	
DW statistic (transformed)				2.4151	
Dependent Variable: Number of Wheat Varieties Released					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	3.11 ***	0.000	0.00	3.18 ***	0.002
PBRs granted	0.40 ***	0.004	1.00	0.36 ***	0.000
R-square	0.16			0.25	
Chi-square (hettest)	0.62	0.4314			
DW statistic (original)	1.7956			1.7956	
DW statistic (transformed)				1.9903	

Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = $p < 0.01$.

The empirical results from the multiple regression analyses using all the variables of the IPRs are presented in Tables 6 and 7 below. Table 6 presents the results with the PBRs granted variable disaggregated between PBRs granted for wheat varieties released by the ARC-SGI and Sensako. Table 7 shows the results with the aggregated PBRs granted variable. An additional variable added is the dummy variable for the years South Africa amended the Plant Breeders' Rights Act to confirm with the constitution and UPOV 1991. The results show that for the first regression with disaggregated PBRs granted variable, the robust estimate of the IPR Index for the wheat productivity variable is positive and statistically significant. The coefficient of the same variable is also positive and significant with the dependent variable of number of wheat varieties released.

The results further suggest the strong relationship between wheat productivity and release of new varieties and strengthening of IPRs systems in the country. As reviewed in the literature section above, strengthening of the IPRs for plant varieties results in an increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth [5,6]. On the contrary, as indicated earlier, the relationship between release of new varieties and IPRs systems is not that strong and is negative (Table 7). Furthermore, although the robust coefficients of the other IPRs variables are positive, they are not all statistically insignificant for all scenarios. The results also suggest that the relationship between PBRs granted might not have a very strong relationship with wheat productivity and the number of wheat varieties released. This indicates that there is need for more incentives beyond granting PBRs to be provided in the whole wheat sector to stimulate increased investments and release of new varieties.

Table 6. Multiple regression model of wheat yield/number of varieties released and IPRs.

	OLS Parameters			Cochrane-Orcutt AR (1) Parameters	
Dependent Variable: Wheat Productivity					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	8.70 ***	0.000	0.00	8.70 ***	0.000
IPR Index	0.41 ***	0.000	3.51	0.41 ***	0.000
PBR_{ARC}	0.02	0.557	1.22	0.003	0.866
PBR_{DP}	0.02	0.176	1.72	0.02 **	0.001
$PBRAct_t$	0.04	0.718	3.55	0.02	0.906
R-square	0.87			0.72	
Chi-square (hettest)	2	0.1572			
DW statistic (original)	1.1227			1.1227	
DW statistic (transformed)				1.7622	
Dependent Variable: Number of Wheat Varieties Released					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	1.35 **	0.093	0.00	1.46 **	0.010
IPR Index	1.40 **	0.020	3.18	1.24 **	0.044
PBR_{ARC}	0.38	0.360	1.45	0.60 *	0.056
PBR_{DP}	0.03	0.881	1.72	0.05	0.793
$PBRAct_t$	−0.94	0.500	3.16	−0.83	0.570
R-square	0.27			0.35	
Chi-square (hettest)	0.46	0.4998			
DW statistic (original)	2.2077			2.2077	
DW statistic (transformed)				1.9894	

Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$.

Despite the importance of the Ordinary Least Squares (OLS) regression in explaining relationships between variables, for example, in the case of this paper, between wheat productivity and IPRs systems, the approach has some limitations. The approach by nature considers a linear (or straight line) relationship between the dependent and explanatory variables, however, this might not always be the case. With additional data, different functional forms and specifications of the relationships between the dependent and explanatory variables should be explored in future research on similar

issues. Another limitation is that the OLS method is sensitive to presence of outliers and it is important to have the data cleaned of outliers before running the regression model/s. Other limitations relate to cases when the OLS method is applied in cases where there are problems of multicollinearity, heteroscedasticity and autocorrelation, as discussed above. As with any econometric estimations, running diagnostic tests and corrective measures is important when using the OLS method.

Table 7. Multiple regression model of wheat yield/number of varieties released, IPRs and aggregate PBRs granted.

	OLS Parameters			Cochrane-Orcutt AR (1) Parameters	
Dependent Variable: Wheat Productivity					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	8.69 ***	0.000	0.00	8.69 ***	0.000
IPR Index	0.42 ***	0.000	3.51	0.044 ***	0.000
PBRs granted	0.0008	0.952	1.76	0.005	0.505
PBRAct_t	0.09	0.465	3.57	0.05	0.743
R-square	0.86			0.70	
Chi-square (hettest)	1.35	0.2451			
DW statistic (original)	1.1415			1.1415	
DW statistic (transformed)				1.7860	
Dependent Variable: Number of Wheat Varieties Released					
Variable	**B**	**Pr > |t**	**VIF**	**B**	**Pr > |t**
Constant	1.42 **	0.074	0.00	1.41 **	0.034
IPR Index	1.33 **	0.026	3.19	1.34 **	0.047
PBRs granted	0.19	0.267	1.73	0.19	0.320
PBRAct_t	−1.05	0.449	3.24	−1.08	0.526
R-square	0.28			0.26	
Chi-square (hettest)	1.01	0.3160			
DW statistic (original)	1.9689			1.9689	
DW statistic (transformed)				1.98941.9917	

Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = $p < 0.01$, ** = $p < 0.05$,

5. Conclusions

The paper analyzed the effects of strengthening wheat variety intellectual protection on wheat productivity and the release of new varieties. The strength of IPRs systems was measured using an IP protection index, plant variety protection legislation and the number of plant breeders' rights granted for wheat varieties. Analysis of changes in the roles of public and private wheat research based on shares of varieties in the national commercial crop showed that the wheat sector reforms resulted in the structural transformation of the wheat seed sector market. This led to the reduction of the share of the market share of public-produced wheat varieties in the national crop from above 50% in 1997 to less than 2% in 2015, while that of the private sector (particularly Sensako) rapidly increased from 37% to 96% in the same period.

The empirical analyses were based on correlation and multiple regression analyses. The correlation analyses results showed that wheat productivity and the number of wheat varieties released correlate with each of the variables representing strengthening of IPRs. Furthermore, correlation analysis showed that for the wheat productivity relationship, the results indicate a higher correlation with PBRs granted for Sensako (domestic private sector) breeding programs compared with those from the ARC-SGI (main public sector actor). However, the correlation values were small for PBRs granted for both ARC-SGI and Sensako varieties indicating that the relationship might be weak. The simple regression model results with IPR Index and PBRs granted as independent variables confirmed the positive and significant relationship between these variables and wheat productivity and the number

of varieties released. The findings demonstrate that strengthening IPRs systems in South Africa contributes to improving wheat productivity and increasing the number of wheat varieties released. Multiple regression analyses results suggest a strong relationship between wheat productivity and the strengthening of IPRs systems in the country. Furthermore, although the robust coefficients of the other IPRs variables are positive, they are statistically insignificant for all scenarios. Although these models have a low R-square, this means that future studies should add more explanatory variables to make the models most explained.

Overall, based on these findings it can be argued that in the South African wheat sector, strengthening PBRs (or IPRs systems) contribute to increased investments and release of wheat varieties. Similarly, increased release of new high yielding varieties contributes to enhancing wheat productivity in the country. However, there is a need for more incentives beyond granting PBRs and strengthening of IPRs systems to be provided in the whole wheat sector to stimulate increased investments and release of new varieties.

Future research should extend the analyses on the effects of strengthening IPRs systems to test the complementarity versus substitution effects in public and private wheat varietal improvement research, which could not be done in the current paper. Further research would be also be required to assess complementarity and substitution effects of the changing roles and how best public and private wheat varietal improvements in the country can be further stimulated to enhance productivity. Furthermore, more research is required on private sector research in the wheat sector and the effects of Sensako's monopoly in the wheat sector. Additional data on variables (such as labor, fertilizer, irrigation and machinery) not included in the current analysis could also be gathered and added to the future analyses.

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