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The effects of Plant Breeders' Rights on wheat productivity and variety improvement in South Africa

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Abstract:

The strengthening of the 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 wheat variety intellectual protection on wheat productivity and release of new varieties. The strength of IPR systems was measured using an IP protection index, and Plant Breeders' Rights 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 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 release of new varieties.

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Abstract

The strengthening of the 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 wheat variety intellectual protection on wheat productivity and release of new varieties. The strength of IPR systems was measured using an IP protection index, and Plant Breeders' Rights 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 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 release of new varieties.

1. Introduction

The global demand for food increases with growing world population projected to be 9.8 billion in 2050 and 11.2 billion by 2100 (United Nations Department of Economic and Social Affairs Population Division 2017). The challenges of increasing world population, global climate change, shortages of irrigation water, degradation of agricultural land increases the need to enhance agricultural productivity. Limited opportunities of 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 (Anderson et al. 2016; Licker et al. 2010; van Wart et al. 2013). Research in varietal innovations particularly for the main food crops such as wheat remains important for increasing agricultural productivity and addressing food security concerns and meeting 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[1] expected to impact on the productivity of agricultural systems (Campi 2017). The International Union for the Protection of New Varieties of Plants (UPOV) established in 1961 advocates for strengthening and harmonization of plant variety protection (PVP) laws and standards (UPOV, 1961). The strengthening of *sui generis* plant IPRs is expected to provide incentives to stimulate investments in plant R&D as development of local seed sector (Tripp et al. 2007). In addition, stronger IPRs are expected to stimulate technology development and transfer and effective utilization of genetic resources that would contribute to enhancing agricultural productivity and economic benefits (Campi 2017).

Despite the above arguments for stronger plant IPRs, empirical research on their effects on agricultural innovations and productivity have produced mixed results. For example, Campi (2017) found significant and positive relationship 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., (2005) found that plant variety protection (PVP) contributed to development of more varieties and positively impacted on 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 impact on productivity is either insignificant or negative (Dutfield 2009).

In addition, some empirical studies have argued that IPRs or PVP systems might not be strong enough to stimulate significant investments in plant breeding research/ innovations (Eaton et al. 2006; Srinivasan and Thirtle 2003; Tripp et al. 2007). For example, Tripp et al., (2007) based on case studies from China, Colombia, India, Kenya and Uganda, found that development of PVP systems in developing countries were inadequate for stimulating development of local commercial seed sector and recommended that efforts need to be integrated in 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 (Campi and Duenas 2016).

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

[1] Other factors that affect agricultural productivity include: capital, land, labour, environmental and climatic factors, technological capabilities (Campi, 2017)

or strengthening of the IPR environment for plants with wheat productivity. In addition, there is no empirical work that has assessed how strengthening wheat variety IPRs have 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 strengthening of IPRs on plant varieties on agricultural productivity, 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 (release of new improved varieties). Stronger intellectual property rights are expected stimulate investments in wheat productivity and varietal improvements. The strength of IPR systems was measured using an 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: the next Section discusses the review of literature on the effects of IPRs on agricultural development. Based on the review, hypotheses are proposed for the current study. The methodology and data of the study is presented in Section 3. Section 4 presents and discusses the empirical estimation results. The conclusions and recommendations are presented in Section 5.

2. 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 provides exclusive rights to the breeder to benefits 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 (Louwaars et al. 2009). For example, the main factors that contributed 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 helped protect innovations from being imitated without permission (K. Fuglie et al. 2012; K. O. Fuglie and Toole 2014; Pray and Fuglie 2015). Overall, the strengthening of the IPRs for plant varieties is expected to provide incentives for breeding companies to invest more resources in plant breeding. Strengthening of IPRs for plants is expected to result in increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth (Campi 2017; Tripp et al. 2007).

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 might affect breeding programs although there might be legislative exceptions that provide access to such material for R&D purposes (Campi 2017). The protection from the IPRs can lead to high concentration and creation of monopolistic actors in seed input markets that adversely impacts on local innovations, market development and productivity (Campi and Duenas 2016; Dutfield 2009). On the contrary, Wright and Pardey (2006) 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 (Campi 2017). This means research on the effects of IPRs on wheat productivity provides 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 for the years 1961 to 2011 Campi (2017) 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 might not have positively impacted on commercial wheat productivity in South Africa.

Spielman and Ma (2016) 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., (2012) analyzed the effect of strengthening IPRs systems in TRIPS member countries on agricultural gross domestic product (GDP) for the period 1980 - 2005. The two variables were found to be positively related in both developed and developing countries.

Pray and Nagarajan (2014) found that in India, strengthened IPRs allowing innovators to patent their innovation positively impacted on private agricultural research. Flister and Galushko (2016) 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 IPR systems would contribute to stimulating private sector investments in agricultural R&D.

Kolady and Lesser (2009) analyzed the impacts of the implementation of PVP to crop productivity in the Washington State in 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). In addition, implementation of PVPs resulted in 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 TRIPS commitments can affect both release of high yielding varieties, and private sector investments.

Naseem et al., (2005) examined the effects of PVP and cotton yields in the United States. The empirical findings found that PVP contributed to 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 (1991) 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 stronger IPR environment would stimulate further investments in wheat varietal improvements and release of improved varieties that would contribute to improve productivity.

Tripp et al (2007) 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 (2005) investigated the role IPRs in 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 IPR 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 IPR systems contributing even small role in developing countries.

Dosi et al., (2006) analyzed the relations between appropriability, opportunities and rates of innovation. The evidence from the study suggested that IPRs were not 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 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 (2002) analyzed the effects of the PVP Act (PVPA) of 1970 in the United States on wheat genetic improvement. The PVPA was expected to

strengthen IP protection for plant breeders stimulate investments in varietal R&D, 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 didn't have much impact on excludability in wheat varieties.

Based on this review of literature the following hypotheses are proposed:

> H_1: Strengthening Plant Breeders' Rights in South Africa increased investments and release of improved wheat varieties.
>
> H2: Strengthening Plant Breeders' Rights in South Africa positively and significantly impacted on wheat productivity.

The above discussion 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 considers, imperfect data etc. Campi (2017) 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 context and sectors. The current study contributes to the growing knowledge in this field through analyzing the effects of Plant Breeders' Rights and IPRs systems in the South African wheat sector on the release of new high yielding varieties and wheat productivity. The proposed hypotheses are empirically tested below.

3. Research methodology

The methodology used to analyze the relationships between Plant Breeders' Rights and wheat commercial yields/ 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 (2017)

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 of 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 (Nhemachena et al. 2016), and the IPR index developed by Campi and Nuvolari (2015).

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 1961-2011. 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 (Campi and Nuvolari 2015). 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., (2016). 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 (Alston and Venner 2002; Campi 2017; Falvey et al. 2006; Payumo et al. 2012) that have explored the relationship between IPR systems and agricultural productivity, the empirical analyses of the effects of IPR 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 IPR 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:

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \qquad (1)$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \quad (2)$$

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 IPR protection in year t and μ_t is the error term.

To further explore the relationships between IPR systems, Plant Breeders' Rights and wheat productivity and 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 were added as independent variables. The PBRs granted to Pannar the other key private sector actor were not included since the numbers were very small. 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.

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 PBRAct_t + \mu_t \quad (3)$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 PBRAct_t + \mu_t \quad (4)$$

where PBR_{ARC_t} and PBR_{SEN_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. The study also explored other characteristics that affect agricultural productivity as explanatory variables

similar to Campi (2017): schooling, agricultural labour, number of tractors in use and total area equipped for irrigation and total consumption of fertilizers. The multiple regression models estimated are defined in equations 5 and 6 below. However, due to high levels of collinearity between these variables for the South African data, these multiple regressions were excluded.

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 \text{PBRAct}_t + \alpha_6 school_t + \alpha_7 \log labour_t + \alpha_8 \log tract_t + \alpha_9 \log fertil_t + \alpha_{10} \log irrig_t + \mu_t \quad (5)$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 \text{PBRAct}_t + \alpha_6 school_t + \alpha_7 \log labour_t + \alpha_8 \log tract_t + \alpha_9 \log fertil_t + \alpha_{10} \log irrig_t + \mu_t \quad (6)$$

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[2]

Variable name	**Description**	**Data source**
logyield	Wheat yield (tonnes/ha)	Campi (2017)
IPR	Index of IPR protection for plant varieties	Campi and Nuvolari (2015)
PBRAct$_t$	Dummy variable for the period the PBR Act was amended	Nhemachena et al., (2016)
PBR$_{ARC}$	Number of PBRs granted for wheat variables released by the ARC-SGI (main public sector actor)	Nhemachena et al., (2016)
PBR$_{SEN}$	Number of PBRs granted for wheat variables released by Sensako (main domestic private sector actor)	Nhemachena et al., (2016)
School	Educational attainment for total	Campi (2017)

[2] 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.

	population aged 15 or over	
loglabour	Agricultural labour per arable land	Campi (2017)
logtract	Agricultural machinery, tractors per arable land	Campi (2017)
logfertil	Fertilizers consumption per arable land	Campi (2017)
logirrig	Total area equipped for irrigation (1000 hectares)	Campi (2017)

4. Empirical results and discussions

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. 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. Details of these data are elaborated in Nhemachena et al., (Forthcoming). 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 1992 when the ARC was established and prior when the Wheat Board was still operational the results indicate 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, mainly Sensako dominating the wheat input market.

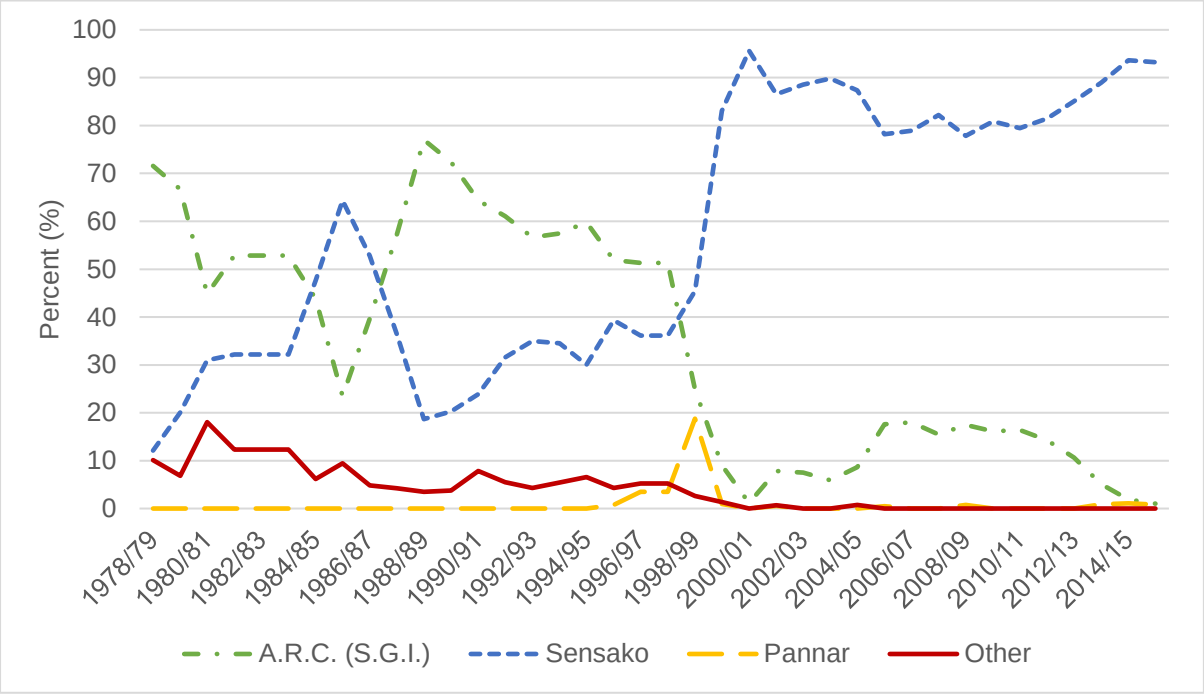

Figure 1: Summary of breeders shares of wheat varieties based on area estimates from cultivar composition in national output

Source: Nhemachena et al., (Forthcoming)

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 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 showed structural transformation of

agricultural input industries after policy reforms that liberalized input sectors (Pray and Nagarajan 2014).

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 (2015) 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 has surpassed that from 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 tend to reduce their R&D investments compared to what they could have invested in the absence of public R&D (Pray and Fuglie 2015). 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 above analysis, it is can also be argued that the deregulation has contributed to concentration of wheat seed markets into a single private actor Sensako which is acting 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 might innovate less taking advantage of their market power (Boldrin and Levine 2004). The creation on monopolistic firms in both genetic resources and seed markets have adverse implications on efforts to enhance agricultural productivity. For strategic and main food crops in a country, it might be of national interest for ensuring public resources are invested in plant breeding and varietal improvement. Though, this could not be

done for the current research, future research can 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/PBRs are presented in Table 2 below. The correlation analysis was also performed for the relationship between number of wheat varieties released and the variables explaining IPRs/PBRs (see 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 (2017) who found no significant relationship between IPR systems and cereal productivity in middle income countries such as South Africa. The findings show that the 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 & PEARSON CORRELATIONS								
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Wheat productivity	9.49	0.54	1.00					
2. IPR	1.81	1.11	0.93***	1.00				
3. $PBRAct_t$	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 < .01, ** = p < .05, * = p < .10*

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

DESCRIPTIVE STATISTICS & PEARSON CORRELATIONS								
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Number of wheat varieties	3.71	2.74	1.00					
2. IPR	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 < .01, ** = p < .05, * = p < .10*

Using rough commonly-held guidelines on the sizes of correlations (Lee 2016), 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 large correlation/ good evidence of association between these variables. The results for the PBRs granted to the ARC-SGI and wheat productivity has a correlation of 0.38 which points to moderate evidence of association between the variables. Furthermore, the correlations between wheat productivity and IPR index and period after amendment of PBR Act to align with the constitution and UPOV 1991 has very big correlations/ strong evidence of association (above 0.80) between the variables. The results points to more influence of Sensako (domestic private sector) developed varieties in the harvested national crop. The findings point to stimulation of private sector investments by stronger IPR systems in the country. As indicated in the review above, evidence from other countries such as India and Brazil demonstrated that private sector investments were stimulated by strengthened IPR systems (Flister and Galushko 2016; Pray and Nagarajan 2014).

In addition, 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). The correlation coefficients were in the range 0.30 to 0.49 which indicate moderate correlations/ evidence of association between the variables. From these results it can be argued that although there is some relationship between number of varieties released and PBRs granted the relationships are not very strong. This might point to the fact that PBRs alone does not have very strong influence on the decisions to invest more in wheat varietal improvements. For example, for private firms, the seed royalties are insufficient to conduct basin research and experiences from Brazil indicated that the private sector directed their investments to more profitable ventures like applied research and development of new cultivars (Flister and Galushko 2016). This means stimulating investments in wheat varietal improvements in South Africa should go beyond strengthening IPR 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 stimulus to investments by the private sector in agricultural R&D (Pray and Nagarajan 2014; Wang et al. 2013). 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 (Pray and Nagarajan 2014). Pedigree analysis of the domestic private sector varieties especially from Sensako (Nhemachena et al.

Forthcoming) 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 delivery of improved wheat varieties and enhance productivity in the country.

4.3. Estimating effects of IPRs/PBRs on wheat productivity and 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 IPR 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 is exist among the regressors, it results in imprecise estimates of the parameters (A Colin Cameron and Trivedi 2005).

The correlation analyses presented above didn't show very high correlations to suspect problems of multicollinearity. Furthermore, multicollinearity was tested based on the variance inflation factor (VIF) (Lee 2016). 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 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 Campi (2017) 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 (White 1980). Incorrect inferences can be drawn if hypotheses are tested in the presence of

heteroscedasticity. To address potential problems of heteroscedasticity, 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 (Adrian Colin Cameron and Trivedi 2010).

The results of a simple regression model of each of the dependent variables and IPR index and number of PBR 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 23% of the variability in wheat productivity and the number of wheat varieties released respectively. For the regressions with the PBR granted as independent variable the models explained 33% and 19% of the variability in the same dependent variables respectively. The coefficients of the IPR index and PBR granted show that both independent variable 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 IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. This confirms to findings discussed in the literature review above from other parts of the world (Knudson and Pray 1991; Kolady and Lesser 2009; Naseem et al. 2005; Spielman and Ma 2016) that strengthening IPR systems stimulate investments in plant breeding, release of new varieties and enhances crop yields.

Table 4: Simple regression model of wheat yield/ number of varieties released and IPR index

	OLS parameters					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.66***		0.000	8.55 to 8.77	0.00	8.68***		0.000	8.55 to 8.81
IPR Index	0.46***	0.93	0.000	0.40 to 0.51	1.00	0.45***	0.92	0.000	0.39 to 0.51
R Square	**0.86**					**0.70**			

Dependent variable: Number of wheat varieties released									
Intercept	**1.52****			0.02 to 2.84	0.00	1.28**		0.041	0.05 to 2.51
IPR Index	**1.27*****			0.62 to 1.91	1.00	1.22***	0.49	0.000	0.62 to 1.83
R Square	**0.25**					**0.23**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

Table 5: Simple regression model of wheat yield/ number of varieties released and PBR granted

	OLS parameters					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	9.30***		0.000	9.16 to 9.44	0.00	9.28***		0.000	9.12 to 9.44
PBR granted	0.11***	0.59	0.000	0.07 to 0.15	1.00	0.11***	0.58	0.000	0.06 to 0.15
R Square	**0.35**					**0.33**			
Dependent variable: Number of wheat varieties released									
Intercept	3.11***		0.000	2.27 to 3.94	0.00	2.67***		0.000	1.90 to 3.45
PBR granted	0.40***	0.41	0.004	0.13 to 0.66	1.00	0.47***	0.50	0.000	0.23 to 0.71
R Square	**0.16**					**0.19**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

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 present the results with the PBR granted variable disaggregated between PBR granted for wheat varieties released by the ARC-SGI and Sensako. Table 7 shows the results with the aggregated PBR 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 PBR 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 positive and insignificant with the dependent variable of number of wheat varieties released.

The results further suggest the strong relationship between wheat productivity and strengthening of IPR systems in the country. As reviewed in the literature section above, strengthening of the IPRs for plant varieties result in increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth (Campi 2017; Tripp et al. 2007). On the contrary as indicated earlier the relationship between release of new varieties and IPR systems is not that strong although it is positive. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios. The results also suggest that the relationship between PBR granted might also 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					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > | t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.70***		0.000	8.56 to 8.83	0.00	8.72***		0.000	8.57 to 8.87

IPR Index	0.41***	0.83	0.000	0.31 to 0.50	3.51	0.39***	0.80	0.000	0.28 to 0.51
PBR_{ARC}	0.02	0.03	0.557	-0.04 to 0.08	1.22	0.02	0.03	0.610	-0.05 to 0.09
PBR_{DP}	0.02	0.10	0.176	-0.01 to 0.05	1.72	0.02	0.09	0.250	-0.01 to 0.05
$PBRAct_t$	0.04	0.04	0.718	-0.19 to 0.27	3.55	0.07	0.06	0.613	-0.19 to 0.33
R Square	**0.87**					**0.73**			
Dependent variable: Number of wheat varieties released									
Intercept	1.35*		**0.093**	-0.24 to 2.93	0.00	1.55**		0.033	0.12 to 2.97
IPR Index	1.40**	0.56	**0.020**	0.22 to 2.58	3.18	0.86	0.35	0.124	-0.24 to 1.96
PBR_{ARC}	0.38	0.14	**0.360**	-0.45 to 1.20	1.45	0.43	0.16	0.254	-0.31 to 1.17
PBR_{DP}	0.03	0.03	**0.881**	-0.36 to 0.42	1.72	0.08	0.08	0.671	-0.28 to 0.44
$PBRAct_t$	-0.94	-0.16	**0.500**	-3.71 to 1.84	3.16	0.10	0.02	0.942	-2.54 to 2.74
R Square	**0.27**					**0.27**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

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

	OLS parameters					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**B**	**Pr > | t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.69***		0.000	8.55 to 8.83	0.00	8.72***		0.000	8.56 to 8.87
IPR Index	0.42***	0.86	0.000	0..32 to 0.52	3.51	.041***	0.83	0.000	0.29 to 0.52
PBR granted	0.0008	0.004	0.952	-0.03 to 0.03	1.76	0.003	0.01	0.886	-0.03 to 0.03
$PBRAct_t$	0.09	0.08	0.465	-0.15 to 0.32	3.57	0.10	0.09	0.450	-0.16 to 0.37
R Square	**0.86**					**0.71**			
Dependent variable: Number of wheat varieties released									
Intercept	1.42*		0.074	-0.14 to 3.00	0.00	1.58**		0.034	0.12 to 3.03
IPR Index	1.33**	0.53	0.026	0.17 to 2.50	3.19	0.90	0.36	0.116	-0.22 to 2.02
PBR granted	0.19	0.19	0.267	-0.15 to 0.52	1.73	0.24	0.25	0.155	-0.09 to 0.56

$PBRAct_t$	-1.05	-0.18	0.449	-3.82 to 1.72	3.24	-0.11	-0.02	0.934	-2.84 to 2.61
R Square	**0.28**					**0.26**			

Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10

5. Conclusions

The paper analyzed the effects of strengthening wheat variety intellectual (IP) protection on wheat productivity and release of new varieties. The strength of IPR 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 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 PBR granted for Sensako (domestic private sector) breeding programs compared to 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 PBR 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 IPR systems in South Africa contribute to

improving wheat productivity and increasing the number of wheat varieties released. Multiple regression analyses results suggested a strong relationship between wheat productivity and strengthening of IPR systems in the country. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios.

Overall, based on these findings it can be argued that in the South African wheat sector, strengthening PBRs (or IPR systems) contribute to increased investments and release of wheat varieties. Similarly increased release of new high yielding varieties contribute to enhancing wheat productivity in the country. However, there is 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 release of new varieties.

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