AGRICULTURAL ECONOMICS

Agricultural Economics 48 (2016) 1–13

The effect of intellectual property rights on agricultural productivity

Mercedes Campi*

Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), University of Buenos Aires. Instituto Interdisciplinario de Economía Política de Buenos Aires (IIEP-Baires, UBA)

Received 4 April 2016; received in revised form 23 August 2016; accepted 25 August 2016

Abstract

This article explores how the strengthening of intellectual property (IP) protection affects agricultural productivity in a panel of countries for the period 1961–2011. Using an index of IP protection for plant varieties, we study the effect of stronger intellectual property rights (IPRs) on cereal yields and two different types of cereals: Open-pollinated (wheat) and hybrid (maize). We found that the strengthening of IPRs has a positive effect on productivity of cereals for high- and low-income countries. However, we found no significant effect for middle-income countries. In addition, we found that becoming a member of the Trade Related Aspects of Intellectual Property Rights negatively affects cereal yields. Finally, we found evidence of the existence of nonlinearities in the effect of IPRs on agricultural yields, which confirms a threshold effect of IPRs that also varies for countries of different income level. The findings support the hypothesis that country specificities are important in determining the effect of IPRs and imply that there is no unique system that fits all.

JEL classifications: O10, O34, O50, Q19

Keywords: Intellectual property rights; Productivity; Agriculture; International comparison

1. Introduction

Recent changes in global population have raised new challenges for agriculture, mainly related with feeding a growing population with changing dietary preferences and consumption patterns. This objective has to be achieved with a decreasing quantity of available agricultural land and considering the need to attend several environmental concerns (Conway and Toenniessen, 1999; Godfray et al., 2010; Marchal et al., 2012). There exists a broad consensus on the need for major changes in the global food system toward a more productive but also more sustainable system. In the meantime, there is a contentious debate on how to attain this aim.

The number and composition of population and food demand have been changing leading to an increase in competition for scarce land. This implies that increases in production to feed a growing population will have to be obtained from increases in productivity derived from two sources: (1) technological changes, and (2) restoration of degraded soils and improvement in soil quality.

Several factors affect agricultural productivity: Capital, labor, and land availability, environmental and climatic factors, technological capabilities, profitability, and institutional factors. Among the institutional factors, recent changes in intellectual property rights (IPRs) systems are generally expected to affect agricultural productivity in several ways.

However, there is no consensus on how IPRs affect innovation and productivity. Some authors argue that tighter IPRs systems in agriculture are likely to increase productivity by increasing incentives to create and diffuse new and more productive plant varieties (see, for example, Kolady and Lesser, 2008; Naseem et al., 2005). Conversely, other scholars argue that IPRs might have a nonsignificant or negative impact on productivity, especially for farmers in developing countries, by decreasing biodiversity, increasing concentration, and reducing availability of new plant varieties (see, for example, Dutfield, 2009; Kloppenburg, 2004).

The International Union for the Protection of New Varieties of Plants (UPOV) advocates for harmonized and strong sui generis IPRs systems in the agricultural sector, and argues that an effective intellectual property (IP) protection system will provide an incentive to stimulate new and more effective breeding work at the domestic level (UPOV, 2005). It also argues that, in an international context, IPRs systems can provide important benefits by removing barriers to trade, thereby

*Corresponding author. Tel: +54 11 5285–6578.
E-mail address: mercedes.campi@fce.uba.ar; mmcampi@gmail.com (M. Campi)

DOI: 10.1111/agec.12337

increasing domestic and international market scope. Moreover, the UPOV holds that access to foreign-bred varieties enabled by IPRs would improve production and exports. Thus, the UPOV considers that IPRs are an important means of technology transfer, an effective utilization of genetic resources, and a means to achieve higher yields and economic benefits.

Conversely, several authors have raised concerns regarding potential negative effects on domestic industries of developing countries derived from the monopoly power of IPRs, which may deter local innovation, productivity, technology transfer, and trade (Boldrin and Levine, 2010; Campi and Dueñas, 2016). In addition, the effect of strengthening IPRs in developing countries is controversial and was theoretically criticized, for example, by Helpman (1993), and empirically, for instance, by Louwaars et al. (2005).

Despite this ongoing debate, there is a global progressive tightening of IP protection systems, especially since the signing of the agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS; Maskus, 2000; Orsi and Coriat, 2006). However, IPRs systems need to be discussed and could be reformed if needed. Thus, empirical studies addressing the effects of IPRs in different sectors and countries are necessary in economics.

This article studies how IPRs are related with agricultural productivity. As an indicator of productivity, we use yields of cereals, defined as the total production in tons obtained over the total area harvested in hectares.[1] As a measure of IPRs, the article uses an index that quantifies the strength of IP protection for plant varieties (Campi and Nuvolari, 2015). The index takes a cross-country and historical perspective, being computed for a group of 69 countries, both developed and developing, and for a period of 51 years (1961–2011). The set of countries includes member of the UPOV convention because they have comparable legislation on IPRs for plant varieties. The index consists of five components that altogether indicate the strength of each country's IP protection system for plant varieties. The index shows that the mean of protection has been steadily increasing over time.

We investigate the effect of IPRs on cereals yields controlling for other productivity determinants such as machinery, agricultural labor, human capital, and other agricultural inputs. In particular, we aim to study whether the tightening of IPRs systems affects productivity of cereals, and if the effect of IPRs is different for countries of different income level.

In addition, we study how the different components of the index affect productivity, in particular, we are interested in two exceptions considered by plant breeders' rights (PBRs). The first one is the farmers' right to save seeds, and the second one is the breeders' exception that allows breeders to use protected material for carrying out research and development (R&D) leading to innovation.

Besides, we analyze the effect of IPRs at a more disaggregated level for two relevant cereals (maize and wheat), which have specific characteristics that lead to different expected effect of IPRs. Most used maize seeds are hybrids, which lose their traits in the second generation, not allowing farmers to reuse the harvested seeds. Meanwhile, because wheat is an open-pollinated variety, farmers can reuse the harvested seeds maintaining their genetic characteristics. These features imply that the imitation threat is different for these two crops and also that the incentives of a tighter IPRs system might be different. In the case of maize, seed saving is discouraged given that most used varieties are hybrids and they offer a natural protection (Campi, 2014; Galushko, 2012). Thus, IPRs could have a minor role in hybrids. Conversely, we might expect a stronger effect of IPRs in open-pollinated varieties such as wheat.

Finally, we also explore the possibility of a non-linear relation between yields and IPRs, for different levels of IPRs, and countries of different income levels and yields.

The existing evidence on this topic is mixed and it is mostly based on cases of study for different crops or countries. This article contributes to the ongoing debate providing a cross-country study for a time period of 51 years. The results of the econometric estimations show that the general rise of the IP index score over time is positively correlated with yields when considering the full sample of countries. However, we found heterogeneous effects when checking the robustness of the results for countries of different income levels. The correlation is positive and significant for high- and low-income countries but not significant for middle-income countries. We also found evidence on the existence of nonlinearities in the relation between yields and IPRs. In particular, for middle- and low-income countries, the effect of IPRs depends on the strength of the systems.

The remaining of the article is organized as follows. Section 2 discusses the expected effect of IPRs on yields, and the specificities of IPRs systems in agriculture. Also, provides a brief literature review of empirical studies on the effect of IPRs on R&D, innovation, and agricultural productivity. Section 3 analyses empirical evidence of the relation between yields and our measure of IPRs. Section 4 presents multivariate econometric estimations to further study this relation for the panel data. Finally, Section 5 presents the main conclusions.

2. How are IPRs and productivity related?

Whether IPRs affect R&D, innovation, productivity, and economic growth, is still a matter of a contentious debate in economics. One of the key issues of the debate lies in how firms manage to appropriate the benefits deriving from their innovations, and how this impacts on innovation, productivity, and economic growth.

Standard economic theory postulates that, by granting a temporary right, IPRs allow firms the appropriation of innovation rents and, by doing so, encourage allocation of resources for R&D that will likely result in innovation and productivity growth (Arrow, 1962; Romer, 1990). This view, based on the existence of a "market failure," has been theoretically criticized

[1] Data are from FAOSTAT (www.faostat.fao.org).

by several economists (see, for example, Helpman, 1993). Dosi et al. (2006) claim that while the main determinants of innovation rates rest within technology-specific and sector-specific opportunity conditions, the differential ability of individual firms to benefit from them derives from idiosyncratic organizational capabilities rather than from IPRs systems. In addition, the monopoly power derived from IPRs can be detrimental to innovation and very costly for society (Boldrin and Levine, 2010).

The use of IPRs as tools to spur innovation in the manufacturing sector has been sharply criticized. Several empirical contributions have proved that, in order to protect the profits of inventions, firms use a wide range of mechanisms, other than patents, such as secrecy, lead time advantages, cost and time required for duplication, learning, and the use of complementary marketing and manufacturing capabilities (Cohen et al., 2000; Mansfield, 1986).

Specific features of the agricultural sector add more complexity to this debate. IPRs are used to protect seeds, which are both capital goods (seeds) and final goods (grains), raising a special problem when the harvested grain is used a seed. This issue regards the scope of IPRs and their exhaustion. Some IP legislation consider the farmers' right to save grains for their use as seeds, avoiding the controversial problem of the extension of the right that enables to control the use of IP protection after sale (Boldrin and Levine, 2010). The farmers' right aims to recognize the incremental contribution of farmers over prior decades to developing new crops.

Also, innovation in plant varieties is based on the use of existing genetic material. Therefore, access to genetic material is essential to obtain new plant varieties and the restrictions to use protected plant varieties are especially problematic in this sector. This issue is considered in some legislation by allowing the breeders' exception, which allows breeders to use protected material in their R&D activities to obtain new plant varieties.

Being living organisms, IP protecting of seeds brings also moral and ethical questions to the debate. IPRs restrict access to assets that are key to ensure food security. The restrictions to control and access genetic resources also negatively affect food sovereignty. These problems are particularly severe in developing countries, given that most genetic resources are being appropriated by companies of developed countries. Although, some scholars argue that the fact that multinational companies often do not protect their technologies in less developed countries (LDC), leaving them freedom to operate, LDC are not always capable of using these technologies (Goeschl and Swanson, 2000; Srinivasan and Thirtle, 2000). Moreover, IPRs systems in agriculture have led to a high concentration in the seed market (Dutfield, 2009; Moser and Wong, 2015).

The equal system promoted by the UPOV do not consider agricultural features of LDC. This system promotes an agricultural system that leads to monoculture or concentration in a few commercial plant varieties, affecting biodiversity, and the use of traditional knowledge by small farmers in developing countries (Dutfield, 2011; Rangnekar, 2000).

In this article, we focus on the effect of IPRs on agricultural productivity. In the debate, if IPRs act as incentives to encourage investment in R&D and innovation, in turn, this might underpin yield growth. However, the restricted access to innovations derived from the monopoly power conferred by IPRs could instead deter productivity growth. Also, some authors argue that yield improvements since the global diffusion of IPRs might instead be a consequence of scientific developments rather than IPRs (Wright and Pardey, 2006).

Empirically, how IPRs affect productivity is difficult to be determined because the impact of IPRs is hard to be isolated and measured. This is because, often, the effect of IPRs on productivity can be indirectly observed. For the manufacturing sector, Park (2005) found that IPRs did not spur productivity growth directly, but did so indirectly by encouraging investments in R&D, which in turn were found to increase productivity.

While there are several empirical studies addressing the effect of IPRs on innovation and productivity in manufacturing sectors, there is much less evidence in agriculture, and the existing studies offer mixed results. Most of the literature focuses on how IPRs affect agricultural innovation, and only a few studies provide evidence on the effect of IPRs on productivity.

Several authors have found weak, partial, or no evidence supporting the hypothesis that IPRs are effective in stimulating investments leading to innovation in plant varieties and productivity growth. Alston and Venner (2002) found that the strengthening of IP protection for plant varieties in the United States have spurred only public investment in wheat varietal improvement, but did not cause an increase in experimental or commercial wheat yields. Léger (2005) showed that IPRs played no role in the Mexican maize breeding industry. In a study carried out for five countries, Louwaars et al. (2005) found that IPRs for plant varieties are not a necessary condition for the initial private seed sector development, but they may contribute to its growth and diversification. They concluded that the nature and extent of this contribution will depend on the characteristics of the national seed system. For the case of hybrid corn, Moser et al. (2013) have shown that most patented hybrid corns did not improve significantly on prior ones in terms of yields.

Conversely, there is a number of empirical contributions, which found positive linkages between IPRs, R&D, and agricultural productivity. Naseem et al. (2005) found that PBRs have led to a greater development of more productive varieties with a positive impact on cotton yields in the United States. Likewise, Kolady and Lesser (2008) showed that PBRs have contributed to genetic improvement of wheat varieties in Washington State (US). Using these findings, they developed a model and extended their conclusions to developing countries (Kolady and Lesser, 2009). Similarly, employing data for 103 countries, Payumo et al. (2012) investigated the relationship between strengthened IPRs systems and agricultural development, which was represented by agricultural gross domestic product. They found a positive correlation between these two variables both for developed and developing countries. Similarly, Perrin (1999) argued that without IPRs it is unlikely that agricultural productivity rates in developing countries would be able to catch up with those in developed countries. Spielman and Ma (2015) found that biological and legal forms of IPRs promote yield gap convergence between leaders and followers, although the effect is crop-specific.

The causes for these mixed findings are multiple. One explanatory factor is that the effect of IPRs depends on specificities of technologies and sectors, as well as on the development level of countries (Dosi et al., 2006; Teece, 1986). This prompts the consideration that heterogeneity of the involved countries may probably confound the relation between IP protection and innovation or productivity. Another reason is that the studies assessing these relations rely on imperfect data. Moreover, causality is not always uniquely determined in the relationship between IPRs and productivity or innovation. It is possible that more innovative and productive countries may be more likely to implement stronger IP protection systems. Therefore, institutional arrangements, such as IPRs systems, might be, to a certain extent, the consequence and not the cause of innovation and productivity growth.

The literature reviewed in this section encompasses valuable empirical cases of study that feed the debate. The mixed results and the open discussion demand further investigations. As a contribution to this debate, this article provides a cross-country analysis of the effect of IPRs for plant varieties on agricultural productivity for 51 years (1961–2011).

3. Intellectual property rights and agricultural yields: A preliminary outlook

This section presents empirical evidence of the relation between IPRs and productivity in the production of cereals. Productivity is measured by yields, which are defined as the total output in tons obtained in a year divided by the total area harvested in hectares. Yields constitute one of the possible measures of productivity among others that are commonly used, such as, output per worker or total factor productivity (Mundlak, 2005). Like all productivity indicators, yields present some drawbacks. This indicator is a single-dimensional measure, it adds quantities of non-homogeneous products, it may be affected differently by land quality, and it may be biased by differences in capital and labor intensities.

Nevertheless, we use yields because this measure presents several advantages with respect to other indicators. First, the data to construct this indicator is more reliable compared with the data needed to calculate, for example, total factor productivity. Second, being based on quantities, output per hectare avoids the problem of price input measures for determining how much prices vary per constant-quality unit (Griliches, 1968). Third, unlike total factor productivity, this indicator does not make the assumption that technology is homogeneous; nor it is represented by a well-defined production function in which an improvement in technology with inputs held constant increases the average productivity of all inputs (Mundlak, 2005; Nelson, 1981). Last, but not less relevant, yields reflect, to a major extent, the effect of technical change in agriculture. During the 20th century, the sources of agricultural productivity growth mainly derived from biological innovations, fertilization, and culture techniques, rather than mechanization (Kloppenburg, 2004; Olmstead and Rhode, 2008).[2] Most agricultural economists agree that: "Prior to the beginning of the twentieth century, almost all increases in crop and animal production occurred as a result of increases in the area cultivated. By the end of the century, almost all increases were coming from increases in land productivity—in output per acre or per hectare. This was an exceedingly short period in which to make a transition from a natural resource based to a science-based system of agricultural production." (Ruttan, 2002, 161). Thus, the kind of technical change that has characterized agriculture in the past century is more likely to be reflected in output per hectare than in labor productivity or in total factor productivity, which assumes fixed input coefficients.

We built our indicator of productivity using information provided by FAOSTAT (faostat.fao.org). The indicator includes yields of: Barley, buckwheat, canary seed, cereals nes, grain mixed, maize, millet, oats, quinoa, rice paddy, rye, sorghum, triticale, and wheat.

To quantify the strength and observe the evolution of IPRs systems, we use an index of IP protection for plant varieties, developed by Campi and Nuvolari (2015). This index considers five components that, as a whole, indicate the strength of each country's IP protection system for plant varieties. The components are: (1) ratification of UPOV Conventions, (2) farmers' exception, (3) breeder's exception, (4) protection length, and (5) patent scope.[3] The sum of these equally weighted elements provides a composite index that was shown to represent reasonably well, and in a comparable way, the strength of a country's IPRs system.

The index shows an increase in the mean of protection over time, and that most countries have currently an index score that is above the mean of protection. Like in other sectors, more developed countries have been offering IP protection for plant varieties for many years while LDC have adopted them mainly after the signing of TRIPS agreement, undertaking high levels of IP protection.

Figure 1 illustrates the strengthening of IP protection through different decades. The box plot displays the distribution of the data based on the four quartiles. The upper and lower edges

[2] According to Evenson and Gollin (2003), improvement in cultivars account for 20 to 50% of yield growth in developing countries between 1960 and 2000.

[3] The component patent scope indicates whether patents are allowed in five specific domains related to plant breeding and agriculture: (i) food, which processes products from agriculture; (ii) plants and animals (when the invention is not limited to a specific variety); (iii) microorganisms, which are closely related to the application of genetic engineering to plant breeding; (iv) pharmaceutical products because their production may also rely on biodiversity and genetic resources; and (v) plant varieties (either sexually or asexually reproduced). While many countries regarded some or all of these domains as not patentable subject matter, after the signing of the TRIPS agreement most countries have been including them in their patent systems.

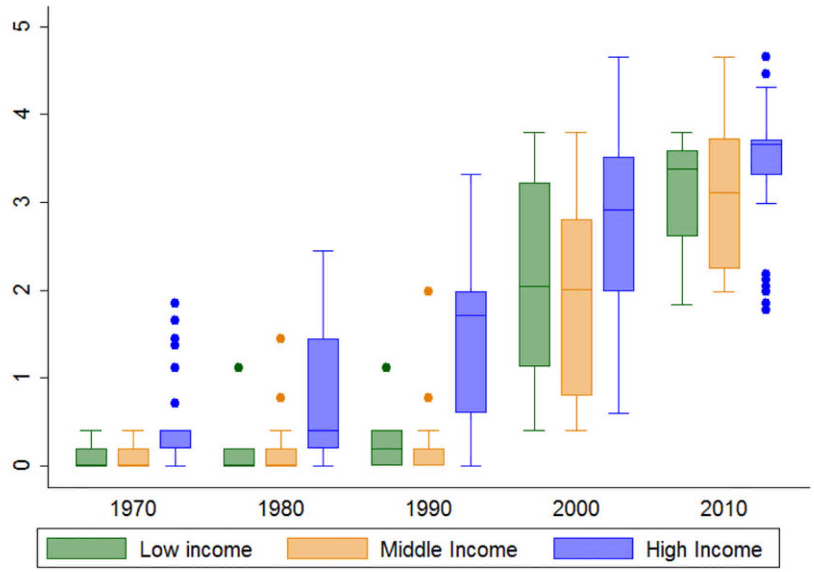


Fig. 1. Evolution of the IP protection index according to income level.

show the index for the higher and lower percentile country. In the boxes of the middle, we observe the two and third quartiles. The horizontal mark is the median index and the dots are the outliers. Countries are sorted according to income level in three groups: high, middle, and low. The income-level classification is taken from United Nations (2013) that classifies countries using data of the year 2011 as high income that are both OECD and non-OECD High Income economies, middle income that are upper middle income, and low income that includes both lower middle income and low income. Accordingly, countries with less than $4,035 gross national income (GNI) per capita are classified as low-income countries, those with GNI per capita between $4,036 and $12,475 as middle-income countries, and those with incomes greater than $12,476 as high-income countries.[4]

Figure 1 shows that the index has increased for countries of all income levels over time. Dispersion has fallen, especially in the last decade, also for all groups. While in the first three decades, we observe an increase in the index for high-income countries, after the 1990s, there is a steady increase in the index of low- and middle-income countries. This process is driven by the signing of the TRIPS agreement.[5]

Next, we study the correlation between the average level of IPRs and agricultural productivity. Figure 2 depicts the scatter plot of the correlation between the index of IP protection and cereal yields. The x-axis sort countries according to their GDP per capita, grouping them in three income levels. The y-axis presents the correlations between cereals yields (in log) and the index of IP protection for each country, computed with the observations of the whole period (1961–2011). The black dots are significant correlations, while white dots represent no significant correlations.

Correlations are positive for most countries. However, we observe heterogeneity: Some countries face low levels of correlations in the three groups of income, the values of the correlations are relatively higher for high-income countries, but also we observe high correlations in the group of middle-income countries. Given this evidence, the effect of stronger IPRs on yields may be expected to be different, and linked to the idiosyncratic capabilities and characteristics of countries.

Next, we move our attention to the cross sections to study how this correlation evolves over time. To this end, we propose the simple model,

$$logyields_t = \beta_1 + \beta_2 IPR_t + \mu_t, \tag{1}$$

where $logyields_t$ is the log of yields and IPR_t is the index of IP protection.

Table 1 displays the coefficients estimated every five years between the log of yields and the index of IPRs. The regressions show that the tightening of IPRs over time is positively correlated with cereal yields, during a part of the period considered. However, the effect of IPRs on yields performance presents a decreasing tendency and the coefficients finally turn out not significant in the last three years considered. We have also found the same behavior using the lagged index of IP protection.[6]

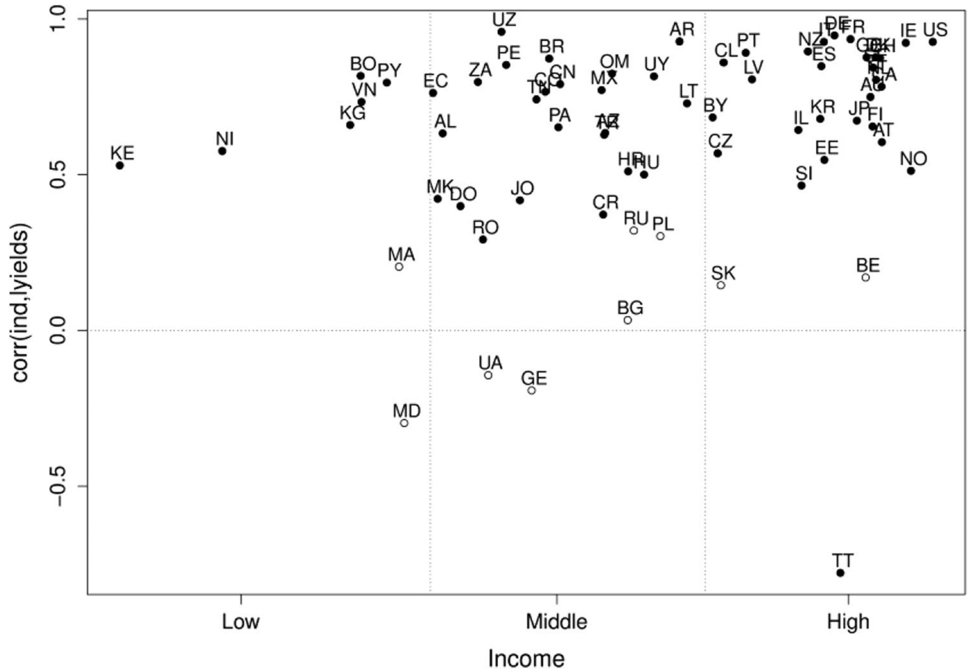
This process is coincident with the increase of the index score for middle- and low-income countries. The greater heterogeneity within developing countries, compared with richer countries, may help understanding the evolution of these correlations.

Finally, it is also plausible to expect different effects and significance of the index of IPRs for different productivity levels,

[4] See the list of countries in the Appendix.

[5] A very similar tendency is also observed for the patent index of Ginarte and Park (1997) for the manufacturing sector. See: Maskus (2000).

[6] The results are available upon request.



Note: Black dots are significant correlations. White dots are no significant correlations. Labels are defined in the Appendix.

Fig. 2. Correlation between yields and IP protection for plant varieties (1961–2011).

Table 1
Correlation between cereals yields and IP protection index

Year	Index		Constant		Observations	R-squared
1965	0.897***	(0.228)	9.589***	(0.076)	48	0.252
1970	0.636***	(0.168)	9.637***	(0.090)	48	0.238
1975	0.470***	(0.120)	9.761***	(0.087)	48	0.250
1980	0.379***	(0.102)	9.896***	(0.086)	48	0.230
1985	0.355***	(0.074)	9.944***	(0.085)	49	0.327
1990	0.312***	(0.065)	10.052***	(0.083)	50	0.324
1995	0.204***	(0.062)	10.013***	(0.102	66	0.145
2000	0.08	(0.062)	10.148***	(0.164)	67	0.025
2005	0.047	(0.060)	10.330***	(0.186)	67	0.009
2010	−0.006	(0.071)	10.560***	(0.237)	67	0.000

Note: The dependent variable is the log of cereals. Standard errors are in parenthesis.
Significance level: $^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.10$.

since more productive countries might be willing to provide higher protection to their agricultural sectors. In order to explore this possible differential impact, we carry on a quantile regression, which provides estimates at different quantiles of the dependent variable.

Figure 3 displays the estimates for the different quantiles of the distribution of the log of yields. The dashed lines represent the ordinary least squares (OLS) estimation with the upper and lower confidence intervals. The OLS estimations do not consider possible heterogeneity in the yields of different countries. Conversely, the quantile regression provides the regressors for each quantile (solid blue line). The shaded area delimits the confidence intervals.

The first plot provides the coefficients for the whole period (1961–2011). We observe that the estimated coefficients are quite close to the OLS estimation for the quantiles in the middle and last part of the distribution. However, for the two lowest quantiles of yields, the effect of IPRs is weaker.

Considering the general changes observed in the index scores after the signing of the TRIPS agreement, we also carried out quantile regressions dividing the data in two sub-periods, before TRIPS (1961–1994) and after TRIPS (1995–2011). The second and third plot in Figure 3 show the results. Before the signing of the TRIPS, we observe that the positive correlation between the index of IPRs and yields is lower in the first deciles. The estimated coefficients reach a maximum between the third and the sixth deciles, and they decrease afterwards. Meanwhile, after the signing of the TRIPS, the coefficients are lower in general, meaning that the effect of IPRs on productivity is weaker. Also, the effect is lower for the lowest and highest quantiles of the yields' distribution.

The quantile regressions suggest that the effect of IPRs is nonlinear and depends on the countries' average yields. Also, they suggest that after the signing of the TRIPS agreement, the general increase of IP protection has a weak effect on productivity. Although interesting, these simple regressions might mask more complex relations and could lead to draw mistaken conclusions. Therefore, to further investigate the effect of the strengthening of IPRs for plant varieties on yields, we carry out a multivariate regression.

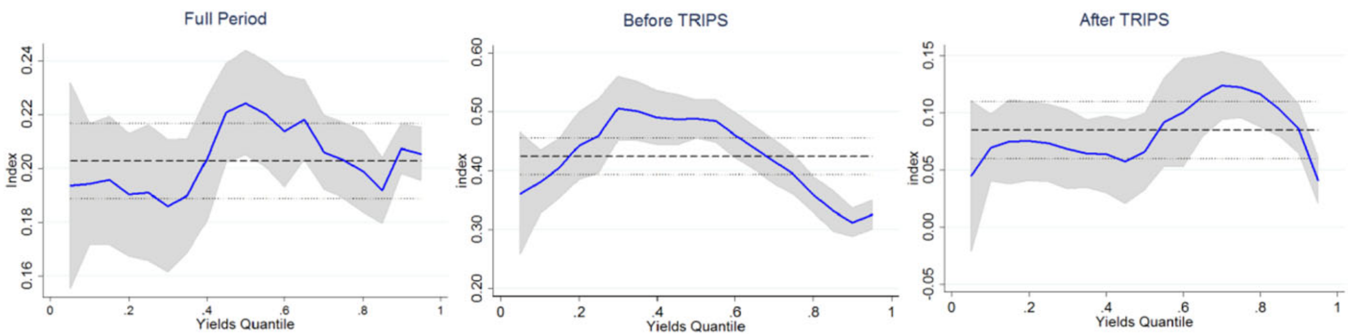


Fig. 3. Quantile regression estimates. Full period (1961–2011), before TRIPS (1961–1994) and after TRIPS (1995–2011).

4. Estimation results

In this section, we develop a multivariate regression using the log of cereal yields (*logcereals*), as the dependent variable, and several independent variables: The index of IP protection (*IPR*), the year in which the countries have complied the terms of the TRIPS agreement (*TRIPS*), and a set of control variables usually considered as determinants of agricultural productivity.

Schooling (*school*) measures the average years of schooling for population of 15 years old and over (Barro and Lee, 2010). This indicator of education attainment is a proxy of the stock of human capital in each country. Given the shift of agriculture and plant breeding toward a more science-based sector, we expect human capital to have a positive effect on productivity. We also include four variables divided by arable land[7] in order to create comparable indicators: (1) agricultural labor (*loglabor*),[8] (2) the number of tractors in use (*logtract*), as an indicator of the stock of capital, (3) the total area equipped for irrigation (*logirrig*),[9] and (4) total consumption of fertilizers (*logfertil*).[10]

Finally, although all the countries in our sample have signed the TRIPS agreement, they were given different time periods to apply the provisions of the TRIPS.[11] Therefore, we also included a country-specific variable indicating the year in which each country has compiled the demands of the TRIPS agreement (*TRIPS*). This variable aims to capture the different effect of IPRs after the TRIPS that we observed in the previous section.

Table 2 summarizes the independent variables and the data sources. Table 3 shows the correlation matrix and Table A.1 of the Appendix displays the summary statistics.

Table 2
Variables: Description and sources

Variable	Name	Source
Yields of cereals	*logcereals*	FAOSTAT
Index of IP protection for plant varieties	*IPR*	Campi and Nuvolari (2015)
TRIPS agreement	*TRIPS*	WIPO (www.wipo.int)
Educational attainment for total population aged 15 or over	*school*	Barro and Lee (2010)
Agricultural labor per arable land	*loglabor*	Fuglie (2012)
Agricultural machinery, tractors per arable land	*logtract*	FAOSTAT & Fuglie (2012)
Fertilizers consumption per arable land	*logfertil*	FAOSTAT & Fuglie (2012)
Total area equipped for irrigation (1,000 hectares)	*logirrig*	FAOSTAT

Table 3
Correlation matrix of independent variables

	IPR	*TRIPS*	*school*	*loglabor*	*logtract*	*logfertil*	*logirrig*
IPR	1						
TRIPS	0.724	1					
school	0.609	0.439	1				
loglabor	−0.089	0.027	0.120	1			
logtract	0.334	0.156	0.531	0.165	1		
logfertil	0.208	0.131	0.389	0.113	0.682	1	
logirrig	0.066	0.113	0.040	−0.066	0.048	0.266	1

4.1. Cereal yields

To study the effect of IPRs on cereal yields, we first estimate the following baseline model:

$$\begin{aligned} logcereals_{i,t} &= \beta_1 + \beta_2 IPR_{i,t} + \beta_3 TRIPS_{i,t} + \beta_4 school_{i,t} \\ &\quad + \beta_5 loglabor_{i,t} + \beta_6 logtract_{i,t} \\ &\quad + \beta_7 logfertil_{i,t} + \beta_8 logirrig_{i,t} + \mu_{i,t}; \end{aligned} \tag{2}$$

where $t = \{1961, \ldots, 2011\}$.

Taking advantage of the panel structure of the data, we estimated the model using fixed effects (FE) and random effects (RE) estimation methods. The Hausmann test rejected the hypothesis that individual effects are random. Hence, we performed the regressions using FE estimation method.

[7] Arable land includes land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded.

[8] The data for 1980 to 2011 are from FAO. To derive estimates for 1961-1979, Fuglie (2012) extrapolates backwards using the annual growth rates from 1961-1979 previously reported by FAO.

[9] Note that this is an indicator of the stock of irrigation equipment and not of its effective use.

[10] Fuglie (2012) estimates the missing data on FAO using International Monetary Fund annual fertilizer price data, and the International Fertilizer Association.

[11] See detailed information on transition periods at: http://www.wto.org/english/theWTO_e/ whatis_e/tif_e/agrm7_e.htm, accessed on June 2015.

Table 4
Cereal yields and index of IPRs. Fixed effects estimates

Model Sample	(1) FS	(2) HI	(3) MI	(4) LI
IPR	0.050***	0.083***	0.001	0.081***
	(0.006)	(0.009)	(0.010)	(0.018)
TRIPS	−0.040***	−0.067***	0.024	−0.106**
	(0.015)	(0.019)	(0.027)	(0.044)
Schooling	0.105***	0.090***	0.129***	0.080***
	(0.005)	(0.007)	(0.008)	(0.014)
Labor	0.017***	0.028***	0.002	0.002
	(0.003)	(0.004)	(0.006)	(0.010)
Tractors	0.003	0.001	−0.029**	0.175***
	(0.007)	(0.009)	(0.014)	(0.030)
Fertilization	0.134***	0.135***	0.150***	0.063***
	(0.007)	(0.014)	(0.013)	(0.016)
Irrigation	0.055***	0.033***	0.068***	−0.099**
	(0.009)	(0.011)	(0.018)	(0.042)
Constant	8.928***	9.065***	8.717***	8.562***
	(0.051)	(0.102)	(0.090)	(0.144)
Observations	2,526	1,155	954	417
R-squared	0.654	0.636	0.745	0.535
Number of countries	55	24	21	10

Note: The dependent variable is the log of cereal yields. Standard errors are in parenthesis.
Significance level: ***$P < 0.01$, **$P < 0.05$, *$P < 0.10$. FS: full sample, HI: high income, MI: middle income, LI: low income.

In order to exploit the differences among the countries of our panel data, we also check the results discriminating by income level. Table 4 displays the results of the FE estimations for different samples of countries.

The index of IP protection turned out significant for the full sample of countries, and the samples of high-income and low-income countries. However, IPRs are not significant for middle-income countries. Likewise, the signing of the TRIPS agreements has a negative and significant effect for the full sample and the sample of high- and low-income countries. This variable is used to capture the different effect of IPRs systems after the signing of the TRIPS. These findings suggests that the effect of IPRs on cereal yields is not relevant for middle-income countries and that there exists a positive effect in the case of high- and low-income countries. However, the signing of the TRIPS, which implies a general strengthening of IPRs systems, has a negative effect in these two group of countries.

Most of the coefficients of the control variables are significant at the 10% level and present the expected signs. Schooling turned out significant and positive for all the samples, verifying the relevance of human capital for agriculture that has been shifting from a natural resourced-based toward a science-based sector. Labor is significant for the full sample and the sample restricted to high-income countries. Tractors, which is used as a proxy of the stock of capital, is positive and significant for the sample of low-income countries and negative for middle-income countries. This variable can be no significant because tractors might not be a good indicator of the stock of capital but also because other inputs are nowadays more important than capital in agricultural production and productivity. The negative sign in the sample of middle-income countries might be due to decreasing returns to scale of tractors. Irrigation and fertilizers are positive and significant determinants of yields for almost all the estimations. However, irrigation is negative for low-income countries. This can be due to the fact that land that needs irrigation is usually less productive than nonirrigated land. Thus, we can expect both a negative and a positive effect of this variable. The R-squared of the models are relatively high for all the samples.

Table 5
Cereal yields and indicators of IP protection. Fixed effects estimates

Model Sample	(1) FS	(2) HI	(3) MI	(4) LI
UPOV	0.070***	0.103***	0.053	0.108**
	(0.020)	(0.029)	(0.033)	(0.051)
No Farmers' Right	−0.042	0.041	−0.228***	
	(0.028)	(0.033)	(0.049)	
Limited Breeders' Exception	0.058***	0.077***	−0.064**	0.100
	(0.016)	(0.021)	(0.032)	(0.066)
Duration of PBR	−0.015	0.026	0.105**	−0.065
	(0.023)	(0.029)	(0.049)	(0.086)
Patent scope	0.198***	0.185***	0.101**	0.292***
	(0.025)	(0.035)	(0.044)	(0.066)
TRIPS	−0.066***	−0.077***	−0.038	−0.100**
	(0.016)	(0.020)	(0.029)	(0.044)
Schooling	0.101***	0.089***	0.123***	0.073***
	(0.005)	(0.007)	(0.008)	(0.014)
Labor	0.017***	0.028***	0.000	0.005
	(0.003)	(0.004)	(0.006)	(0.010)
Tractors	−0.004	−0.007	−0.032**	0.163***
	(0.007)	(0.010)	(0.014)	(0.030)
Fertilization	0.133***	0.137***	0.129***	0.070***
	(0.007)	(0.015)	(0.013)	(0.017)
Irrigation	0.054***	0.028**	0.102***	−0.089**
	(0.009)	(0.011)	(0.018)	(0.042)
Constant	8.944***	9.042***	8.879***	8.596***
	(0.051)	(0.102)	(0.092)	(0.144)
Observations	2,526	1,155	954	417
R-squared	0.661	0.641	0.756	0.550
Number of countries	55	24	21	10

Note: The dependent variable is the log of cereal yields. Standard errors are in parenthesis.
Significance level: ***$P < 0.01$, **$P < 0.05$, *$P < 0.10$. FS: full sample, HI: high income, MI: middle income, LI: low income.

In the following estimations, we include the five components of the index in order to disaggregate the effects. It should be noted, however, that the purpose of the composite index is to provide a general measure of the strength of IPRs systems in agriculture. Therefore, how an individual component could affect innovation and yields, might be difficult to understand. However, some components could reveal interesting aspects. Also, analyzing the disaggregated components of the index can help us understand the driving forces of the effect of the aggregated index. Table 5 shows the results of the estimations for cereal yields.

We observe that being a member of the UPOV convention is positively correlated with cereal yields for the full sample and for high- and low-income countries. The second component of the index considers whether countries allow the farmers' right to save seeds for the following season considering their contribution to obtain current plant varieties. The indicator takes the value of 1 if countries do not consider this right. The estimations show that not considering the farmers' right has a negative effect on yields of middle-income countries.[12] This is not surprising because saving seeds in many middle- and low-income countries is a widespread practice.

The third component is related to the right of breeders to use protected varieties to carry out R&D to obtain new plant varieties. Recently, several countries have limited this exception including the concept of essentially derived variety, which implies that the exception to the PBRs does not hold when the new variety is considered as essentially derived from the initial one. Then, the indicator takes the value of 1 if the country has limited the breeders' exception for essentially derived varieties. We observe that limiting the breeders' exception is positive for yields of high-income countries but negative for middle-income countries.

An increase in the duration of PBRs positively affects yields in middle-income countries. Finally, allowing patents in five specific domains related to plant breeding and agriculture has a positive effect of yields for all the samples considered.

4.2. *Hybrids and open-pollinated*

Next, we analyze the effect of IPRs at a more disaggregated level, exploring whether there is a different effect on yields for two types of cereals: wheat and maize. These two cereals are among the most relevant in terms of quantity produced and consumed worldwide. They are relevant for our case of study because they have different biological characteristics that derive in different imitation threats. Usually, farmers use part of their harvests as seeds for the following season. However, most types of maize in the market are hybrids, which are the result of crossbreeding inbred lines, which differ in some hereditary factor. Hybrids inherit the best features of their parents and have a better yields performance. Yet, due to the so-called heterosis, hybrids' offspring present much lower yields. This implies that farmers need to buy seeds of hybrid maize each year. This fact provides a nonlegal protection as well as an incentive for breeders to invest in the creation of hybrids. Therefore, we could expect that IPRs would not affect maize breeders. On the contrary, wheat is an open-pollinated variety, which implies that farmers can save wheat seeds from their harvests and use them for sowing the following year given that wheat maintains its features from generation to generation. Certainly, if breeders offer more productive new varieties, farmers will have an incentive to buy them. But, *a priori*, the enforcement of IPRs would be more valued by breeders in the case of wheat compared to the case of hybrid maize.

[12] The variable is omitted for low-income countries because they all accept farmers' right.

Table 6
Yields of maize and index of IPRs. Fixed effects estimates

Model Sample	(1) FS	(2) HI	(3) MI	(4) LI
IPR	0.114***	0.144***	0.079***	0.152***
	(0.011)	(0.015)	(0.018)	(0.024)
TRIPS	−0.125***	−0.089***	−0.139***	−0.178***
	(0.025)	(0.030)	(0.048)	(0.059)
Schooling	0.111***	0.100***	0.138***	0.053***
	(0.008)	(0.011)	(0.015)	(0.018)
Labor	0.026***	0.029***	0.024**	0.001
	(0.005)	(0.006)	(0.010)	(0.013)
Tractors	0.091***	0.088***	0.083***	0.132***
	(0.011)	(0.013)	(0.025)	(0.040)
Fertilization	0.155***	0.160***	0.196***	0.094***
	(0.011)	(0.021)	(0.023)	(0.021)
Irrigation	0.005	−0.064***	0.038	−0.066
	(0.015)	(0.018)	(0.031)	(0.056)
Constant	8.581***	8.561***	8.286***	8.674***
	(0.081)	(0.155)	(0.155)	(0.192)
Observations	2,183	893	873	417
R-squared	0.576	0.658	0.607	0.408
Number of countries	49	20	19	10

Note: The dependent variable is the log of yields of maize. Standard errors are in parenthesis.
Significance level: ***$P < 0.01$, **$P < 0.05$, *$P < 0.10$. FS: full sample, HI: high income, MI: middle income, LI: low income.

Table 6 displays the results of the estimations using the yields of maize as the dependent variable. We observe that the index of IPRs is positive and significant while the signing of the TRIPS agreement is negative and significant, for all the samples considered, including middle-income countries. The rest of the independent variables are in most cases significant and present the expected signs.

Table 7 shows the results of the estimations using the yields of wheat as the dependent variable. We observe that the effect of IPRs is positive and significant for the full sample and for high-income countries. Conversely, the effect is negative for middle-income countries and not significant for low-income countries. The signing of the TRIPS agreement has a negative effect on wheat yields in the full sample and the samples of high- and low-income countries.

Contrary to the expectations, IPRs systems seem to be more relevant for maize yields than for wheat yields. This can imply that IPRs are relevant for firms not because they allow the appropriation of the innovation rents but for other reasons. For example, firms use IPRs to gain market shares by blocking access to protected assets. In fact, despite hybrids have a natural protection, Moser et al. (2013) showed an increase in the number of patented hybrid corn in the United States.

The disaggregation confirms that the effect of IPRs depends not only on country characteristics but also on crops' features. However, the different expected effects derived from crop characteristics were not confirmed. This might imply that IPRs play a role in agricultural productivity, but their effect is not derived from the incentives to innovate but from other reasons. The

Table 7
Yields of wheat and index of IPRs. Fixed effects estimates

Model	(1)	(2)	(3)	(4)
Sample	FS	HI	MI	LI
IPR	0.029***	0.051***	−0.025*	0.029
	(0.008)	(0.009)	(0.014)	(0.026)
TRIPS	−0.063***	−0.072***	0.020	−0.149**
	(0.019)	(0.021)	(0.038)	(0.060)
Schooling	0.104***	0.086***	0.129***	0.142***
	(0.006)	(0.007)	(0.011)	(0.019)
Labor	0.027***	0.012***	0.057***	0.038***
	(0.004)	(0.004)	(0.007)	(0.012)
Tractors	−0.037***	−0.010	−0.149***	0.010
	(0.009)	(0.010)	(0.026)	(0.066)
Fertilization	0.124***	0.122***	0.157***	0.101***
	(0.009)	(0.015)	(0.018)	(0.022)
Irrigation	0.092***	0.100***	0.099***	−0.108*
	(0.010)	(0.011)	(0.022)	(0.062)
Constant	9.162***	9.283***	9.203***	8.393***
	(0.060)	(0.108)	(0.114)	(0.212)
Observations	2,224	1,104	805	315
R-squared	0.545	0.575	0.603	0.451
Number of countries	49	23	18	8

Note: The dependent variable is the log of yields of wheat. Standard errors are in parenthesis.
Significance level: ***$P < 0.01$, **$P < 0.05$, *$P < 0.10$. FS: full sample, HI: high income, MI: middle income, LI: low income.

estimations provide robust evidence on the negative effect on agricultural yields of the general rise of IP protection derived from the TRIPS.

4.3. Nonlinearities between yields and IP protection

The different correlations between the index of IPRs and yields found for different samples may indicate the existence of nonlinearities in this relation. IP protection is likely to display a threshold effect, given that it could be necessary a minimum degree of appropriability to encourage R&D leading to innovation but, above such a threshold, further strengthening of IPRs could instead lead to negative effects and a decrease in innovation rates (Dosi et al., 2006).

In order to explore further this hypothesis, we use two different methods. In the first one, we simply re-estimate Equation (2) including the square of the index of IPRs (IPR^2). In the second one, we construct three dummy variables, which split the index of IPRs in three different levels: $IPR1_{i,t} \leq 1$ (weak), $1 < IPR2_{i,t} \leq 3.0$ (middle) and $IPR3_{i,t} > 3.0$ (strong). Using these new variables that represent different levels of IP protection, we estimate Eq. (2), including in the regression $IPR2_{i,t}$ and $IPR3_{i,t}$, and, naturally, using $IPR1_{i,t}$ as the base for comparison. Table 8 displays the results.

In the first three models, we have included the square of the index to detect the existence of a nonlinear effect of IPRs. Like

Table 8
Nonlinearities in the relation between cereal yields and IP protection

Model	(1)	(2)	(3)	(4)	(5)	(6)
Sample	HI	MI	LI	HI	MI	LI
IPR	0.099***	0.098***	0.097*			
	(0.017)	(0.027)	(0.051)			
IPR^2	−0.004	−0.023***	−0.005			
	(0.004)	(0.006)	(0.013)			
IPR2 (middle)				0.059***	0.064**	0.042
				(0.017)	(0.027)	(0.044)
IPR3 (high)				0.183***	0.017	0.173***
				(0.027)	(0.033)	(0.055)
TRIPS	−0.064***	−0.017	−0.108**	−0.029	−0.008	−0.043
	(0.020)	(0.029)	(0.044)	(0.019)	(0.027)	(0.042)
Schooling	0.090***	0.124***	0.079***	0.105***	0.129***	0.091***
	(0.007)	(0.008)	(0.014)	(0.007)	(0.008)	(0.014)
Labor	0.028***	0.002	0.001	0.028***	0.003	−0.001
	(0.004)	(0.006)	(0.010)	(0.004)	(0.006)	(0.010)
Tractors	−0.001	−0.031**	0.175***	−0.002	−0.032**	0.172***
	(0.009)	(0.014)	(0.030)	(0.009)	(0.014)	(0.031)
Fertilization	0.132***	0.140***	0.062***	0.138***	0.143***	0.060***
	(0.015)	(0.013)	(0.016)	(0.015)	(0.013)	(0.016)
Irrigation	0.030***	0.075***	−0.099**	0.041***	0.074***	−0.089**
	(0.011)	(0.018)	(0.042)	(0.011)	(0.018)	(0.042)
Constant	9.068***	8.783***	8.564***	9.010***	8.767***	8.560***
	(0.103)	(0.091)	(0.144)	(0.105)	(0.091)	(0.146)
Observations	1,155	954	417	1,155	954	417
R-squared	0.636	0.749	0.535	0.621	0.747	0.524
Number of countries	24	21	10	24	21	10

Note: The dependent variable is the log of yields of cereals. Standard errors are in parenthesis.
Significance level: ***$P < 0.01$, **$P < 0.05$, *$P < 0.10$. FS: full sample, HI: high income, MI: middle income, LI: low income.

in the previous estimations, the coefficients of the index are positive and significant for high- and low-income countries. In these two cases, the squared-index turns out not significant. For the case of middle-income countries, the estimated effect of IPRs is now positive and the squared-index of IPRs is negative and statistically significant. This implies the existence of a nonlinear relation between IPRs and yields for middle-income countries and that the return of increasing IP protection diminishes yields.

In models 4–6, we use the new variables that indicate three different levels of IP protection. The estimated results show that, for high-income countries, shifting from a weak level of IP protection toward both a middle and a strong level of IPRs has a positive and statistically significant effect on yields. In the case of middle-income countries, increasing the level of IPRs only up to a certain middle level has a positive effect on yields. For low-income countries, we found that increasing IP protection from a low level toward a middle level has no significant effect on cereal yields. However, changing from a low level toward a high level of IP protection has a positive effect on yields. This could be explained by the fact that low-income countries usually have lower enforcement of IPRs and, therefore, a middle level of IPRs in the context of low enforcement could not be an incentive for innovation activities. Another, plausible explanation could be that IPRs might promote innovation in high-income countries and technology transfer to low-income countries but they can cause loses derived from the reduced scope for imitation in middle-income countries (Falvey et al., 2006).

Overall, these results evidence the existence of nonlinearities reflected in a threshold effect, which is also specific for countries of different income levels.

5. Concluding remarks

Since more than two decades, there is a great pressure for developing countries to adopt strong and harmonized IPRs systems. At the same time, developed countries continue increasing their IP protection. This global process has been taking place despite the fact that there is no clear evidence determining the convenience of strong IPRs systems.

The empirical and econometric analysis performed in this article showed that the strengthening of IPRs for plant varieties has no equal effect on agricultural yields for countries of different income levels. In our estimations, the index of IP protection is positively and significantly correlated with cereal yields of high- and low-income countries. However, increasing IP protection in middle-income countries does not affect cereal yields. In addition, we observed that the general strengthening of IP protection since the signing of the TRIPS agreement had a negative effect on yields.

Also, we investigated whether the effect of IPRs is different for maize and wheat. We expected possible different effects because, being open-pollinated, wheat can be reproduced by farmers without losing its characteristics while maize, being ah hybrid, cannot be reproduced by farmers. However, we found that IPRs are positively correlated with yields of maize for all the samples. In contrast, IPRs are positively correlated with whet yields only in high-income countries, while the correlation is negative for middle-income countries.

These mixed results and the differences for income level and type of crop, lead to analyze the existence of nonlinearities in the effect of IPRs on yields. We econometrically tested this hypothesis and found evidence of nonlinearities in the effect of IPRs, suggesting a threshold effect that is also specific for countries of different income levels. Also, the quantiles regressions provided different estimated coefficients for different yields levels.

The evidence suggests that tighter IPRs do not lead automatically to greater innovation and productivity. We observe a robust and stable effect in the different specifications only for high-income countries. The relation between IPRs and yields is probably mediated and affected by several factors related to the idiosyncratic features of each single country in terms of innovation capabilities, as well as to their distinctive economic, political and social characteristics. This can help understand the different effects in countries of different income or development levels.

The empirical analysis provides strong evidence against the idea that there is a unique system of IP protection that fits all like the one proposed by the TRIPS and the UPOV. On the contrary, these findings support the hypothesis that sector and country specificities are relevant for determining the effect of IP protection and, thus, IPRs systems should be designed considering them.

But also, the adoption of IPRs systems, especially in developing countries, should consider not only the trade-off related to the monopoly power of IPRs and the incentives on innovation and knowledge creation, but also, and more importantly in the agricultural sector, the possible benefits versus the detrimental effects of the appropriation of genetic resources on sustainability, biodiversity, and food security.

Acknowledgments

I am grateful to Alessandro Nuvolari, Marco Dueñas, Giovanni Dosi, Nanditha Mathew, Roberto Bisang, Anabel Marin, and Federico Tamagni for useful comments and suggestions on earlier versions of this article.

Appendix

List of countries

High-income countries

Australia (AT), Austria (AU), Canada (CA), Denmark (DK), Estonia (DO), France (FR), Germany (DE), Hungary (HU), Israel (IL), Italy (IT), Japan (JP), Netherlands (NL), New Zealand (NZ), Norway (NO), Poland (PL), Portugal (PT), Republic

Table A.1
Summary statistics

Variable	Mean	St. Dev.	Min	Max
Full sample				
logcereals	10.19	0.59	7.32	11.94
IPR	1.35	1.36	0	4.66
school	7.55	2.63	0.47	13.10
loglabor	−4.05	3.38	−11.03	2.59
logtract	3.11	1.52	−3.56	6.81
logfert	4.54	1.35	−3.68	9.71
logirrig	−2.25	1.45	−7.96	0.82
High-income countries				
logcereals	10.49	0.51	8.96	11.94
IPR	1.61	1.33	0	4.66
school	8.87	2.13	3.20	13.10
loglabor	−3.57	3.38	−11.03	2.59
logtract	4.09	1.29	−3.56	6.81
logfert	5.31	0.97	1.74	9.71
logirrig	−2.42	1.53	−7.19	0.82
Middle-income countries				
logcereals	9.95	0.52	7.32	11.15
IPR	1.06	11.34	0	4.66
school	6.38	2.22	0.91	11.52
loglabor	−4.85	3.31	−10.23	0.50
logtract	2.40	0.94	−2.75	4.54
logfert	4.09	1.07	−0.30	6.87
logirrig	−2.07	1.33	−7.96	0.26
Low-income countries				
logcereals	9.79	0.46	8.21	10.89
IPR	1.17	1.33	0	3.8
school	5.67	2.64	0.47	11.12
loglabor	−3.76	3.22	−8.71	0.78
logtract	1.79	1.23	−2.07	4.22
logfert	3.17	1.37	−0.37	6.03
logirrig	−2.13	1.41	−5.52	0.07

of Korea (KR), Spain (ES), Sweden (SE), Switzerland (CH), Trinidad and Tobago (TT), United Kingdom (GB), and United States of America (US).

Middle-income countries

Argentina (AR), Brazil (BR), Bulgaria (BG), Chile (CL), China (CN), Colombia (CO), Costa Rica (CR), Dominican Republic (DO), Ecuador (EC), Jordan (JO), Latvia (LV), Lithuania (LT), Mexico (MX), Panama (PA), Peru (PE), Russian Federation (RU), South Africa (ZA), Tunisia (TN), Turkey (TR), and Uruguay (UY).

Low-income countries

Albania (AL), Bolivia (BO), Kenya (KE), Kyrgyzstan (KG), Morocco (MA), Nicaragua (NI), Paraguay (PY), Republic of Moldova (MD), Ukraine (UA), and Vietnam (VN).

References

Alston, J., Venner, R., 2002. The effects of the US Plant Variety Protection Act on wheat genetic improvement. Res. Policy 31(4), 527–542.

Arrow, K., 1962. Economic welfare and the allocation of resources for invention. In: The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton University Press, Princeton, pp. 609–626.

Barro, R., Lee, J., 2010. A new data set of educational attainment in the world, 1950-2010. NBER Working Paper No 15902.

Boldrin, M., Levine, D.K., 2010. Against intellectual monopoly. Cambride University Press, Cambridge.

Campi, M., 2014. Protecting plants: Incentives to innovate and access to biological resources. A historical overview. Available at SSRN: http://ssrn.com/abstract=2478312, accessed March 2015.

Campi, M., Dueñas, M., 2016, Intellectual property rights and international trade of agricultural products, World Dev. 80, 1–18.

Campi, M., Nuvolari, A., 2015. Intellectual property protection in plant varieties. A New worldwide index (1961-2011). Res. Policy 4(44), 951–964.

Cohen, W.M., Nelson, R.R., Walsh, J.P., 2000. Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not). Working Paper 7552, National Bureau of Economic Research.

Conway, G., Toenniessen, G., 1999. Feeding the world in the twenty-first century. Nature 402, C55–C58.

Dosi, G., Marengo, L., Pasquali, C., 2006. How much should society fuel the greed of innovators?: On the relations between appropriability, opportunities and rates of innovation. Res. Policy 35(8), 1110–1121.

Dutfield, G., 2009. Intellectual property rights and the life science industries: Past, present and future. World Scientific, Singapore.

Dutfield, G., 2011. Food, biological diversity and intellectual property: The Role of the International Union for the Protection of New Varieties of Plants (UPOV). QUNO Intellectual Property Issues Paper 9, 1–20.

Evenson, R.E., Gollin, D., 2003. Assessing the impact of the green revolution, 1960 to 2000. Science 300(5620), 758–762.

Falvey, R., Foster, N., Greenaway, D., 2006. Intellectual property rights and economic growth. Rev. Dev.Econ.10(4), 700–719.

Fuglie, K.O., 2012. Productivity Growth and Technology Capital in the Global Agricultural Economy. In: Fuglie, K., Wang, S., Ball, V. (Eds.), Productivity Growth in Agriculture: An International Perspective. CAB International, Wallingford, pp. 335–368.

Galushko, V., 2012. Do stronger intellectual property rights promote seed exchange: Evidence from us seed exports? Agric. Econ. 43 (s1), 59–71.

Ginarte, J., Park, W., 1997. Determinants of patent rights: A cross-national study. Res. Policy 26(3), 283–301.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: The challenge of feeding 9 billion people. Science 327(5967), 812–818.

Goeschl, T., Swanson, T., 2000. Genetic use restriction technologies and the diffusion of yield gains to developing countries. J. Int. Dev. 12(8), 1159–1178.

Griliches, Z., 1968. Agriculture: Productivity and technology. Int. Encycl. Soc. Sci. 1, 241–245.

Helpman, E., 1993. Innovation, imitation, and intellectual property rights. Econometrica 61(6), 1247–1280.

Kloppenburg, J., 2004. First the seeds. The political economy of plant biotechnology. University of Wisconsin Press, Madison, pp. 1492–2000.

Kolady, D.E., Lesser, W., 2008. But are they meritorious? Genetic productivity gains under plant intellectual property rights. J. Agric. Econ. 60(1), 62–79.

Kolady, D.E., Lesser, W., 2009. Does plant variety protection contribute to crop productivity? Lessons for developing countries from US wheat breeding. J. World Intellect. Prop. 12(2), 137–152.

L´eger, A., 2005. Intellectual property rights in Mexico: Do they play a role? World Dev. 33 (11), 1865–1879.

Louwaars, N.P., Tripp, R., Eaton, D., Henson-Apollonio, V., Hu, R., Mendoza, M., Muhhuku, F., Pal, S., Wekundah, J., 2005. Impacts of strengthened intellectual property rights regimes on the plant breeding industry in developing countries. Technical report, commissioned by the World Bank, Wageningen, The Netherlands.

Mansfield, E., 1986. Patents and innovation: An empirical study. Manage. Sci. 32(2), 173–181.
Marchal, V., Dellink, R., Van Vuuren, D., Clapp, C., Chateau, J., Magné, B., Lanzi, E., van Vliet, J., 2012. Climate Change. In: OECD. OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris.
Maskus, K.E., 2000. Intellectual Property Rights in the Global Economy. Peterson Institute Press: All Books. Peterson Institute for International Economics.
Moser, P., Ohmstedt, J., Rhode, P., 2013. Patent Citations and the Size of Patented Inventions. Evidence from Hybrid Corn. Available at SSRN: http://ssrn.com/abstract=1888191, accessed March 2014.
Moser, P., Wong, P., 2015. Competition and innovation: Did Monsanto's entry encourage innovation in GMO crops? Available at SSRN: http://ssrn.com/abstract=2588330, accessed December 2015.
Mundlak, Y., 2005. Economic growth: Lessons from two centuries of american agriculture. J. Econ. Lit. 43(4), 989–1024.
Naseem, A., Oehmke, J.F., Schimmelpfennig, D.E., 2005. Does plant variety intellectual property protection improve farm productivity? Evidence from cotton varieties. AgBioForum 8(2&3), 100–107.
Nelson, R.R., 1981. Research on productivity growth and productivity differences: Dead ends and new departures. J. Econ. Lit. 19(3), 1029–1064.
Olmstead, A.L., Rhode, P.W., 2008. Creating Abundance. Cambridge University Press, New York.
Orsi, F., Coriat, B., 2006. The new role and status of intellectual property rights in contemporary capitalism. Compet. Change 10(2), 162–179.
Park, W., 2005. Do Intellectual Property Rights Stimulate R&D and Productivity Growth? Evidence from Cross-National and Manufacturing Industry Data. In: Putnam, J. (Ed.), Intellectual Property Rights and Innovation in the Knowledge-Based Economy. Industry Canada, Ottawa.
Payumo, J., Grimes H., Wandschneider, P., 2012. Status of national intellectual property rights (IPRs) systems and its impact to agricultural development: A time series cross section data analysis of trips member–countries. Int. J. Intellect. Prop. Manage. 5(1), 82–99.
Perrin, R.K., 1999. Intellectual property rights and developing country agriculture. Agric. Econ. 21(3), 221–229.
Rangnekar, D., 2000. Plant breeding, biodiversity loss and intellectual property rights, Economics Discussion Papers 2000-5, Kingston University, London.
Romer, P.M., 1990. Endogenous technological change. J. Polit. Econ. 98, 71–102.
Ruttan, V.W., 2002. Productivity growth in world agriculture: Sources and constraints. J. Econ. Perspect. 16(4), 161–184.
Spielman, D.J., Ma, X., 2015. Private sector incentives and the diffusion of agricultural technology: Evidence from developing countries. J. Dev. Stud. 52(5), 1–22.
Srinivasan, C., Thirtle, C., 2000. Genetically modified organisms and smallholders in the developing world. J. Int. Dev. 12(8), 1131–1132.
Teece, D., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Res. Policy 15(6), 285–305.
United Nations, 2013. World Economic Situation and Prospects 2013. Technical report, United Nations, New York.
UPOV, 2005. Report on the impact of plant variety protection. Available at http://www.upov.int/export/sites/upov/about/en/pdf/353upovreport.pdf, accessed March 2015.
Wright, B.D., Pardey, P.G., 2006. The evolving rights to intellectual property protection in the agricultural biosciences. Int. J. Technol. Global. 2(1-2), 12–29.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Data Appendix