Welfare Effects of Herbicide-Tolerant Rice Adoption in Brazil

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Selected Poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

Abstract

The study provides the welfare implications of IPRs for the rice growers, and private innovators developing and introducing non-transgenic herbicide tolerant (HT) rice in southern Brazil. The results revealed that under strict IPR enforcement, both producers and innovators would realize larger economic gains. Farmers will continue to capture a substantial share of the total benefits. Sensitivity analysis showed that the benefits from higher yields due to introduction of HT rice technology are primarily captured by producers. It was concluded that IPRs enforcement is more likely to create an adequate economic environment for the private sector to conduct research and to introduce new technologies in Brazil.

Keywords: IPRs, herbicide tolerant, rice, economic surplus model, Brazil

JEL Classifications: Q16, Q19

Introduction

Agricultural biotechnology, especially genetically modified (GM) crops, can be the basis for significant yield gains, reduced cost of production, and higher-quality end products in agriculture (Hareau, Mills, and Norton 2006). However, the development of new technologies requires significant investments in research and development. Due to the public goods' nature of research, the public sector has traditionally played a key role in the development and dissemination of new technologies. Increasingly, it is the private sector that accounts for more research and development (R&D) expenditures relative to the public sector, a shift that has been gradually occurring over the past two decades. Among the many reasons for this shift, the ability of private firms to appropriate the returns of their research through Intellectual Property Rights (IPRs) protection has been critical (Naseem et al, 2010).

IPR regulations for plants and other biological material always remained a controversial and problematic issue. Given the ease with which seeds can be reproduced, farmers have traditionally saved their seeds for planting in subsequent seasons or selling it to other farmers. If the seed is protected by IPRs (such as plant breeder rights or utility patents) the farmers would need to purchase the seed from the innovator and to pay a royalty fee. It can be argued that stronger IPRs are likely to provide a monopoly power to exclusive suppliers of innovation hence capturing the greatest amount of total benefits. However, evidence suggests that multinationals have not been able to capture monopoly rents from their biological inventions to the extent that had been predicted (Pray 2002).

Despite the importance of strong IPRs in economic development, they are often violated especially in the developing countries. This infringement of IPRs affects the distribution of economic benefits in the society, and as a consequence the incentive to conduct R&D for the innovator (Qaim and Janvry 2003). Over the last decade, several studies have attempted to uncover the economic impact of new proprietary agricultural biotechnology (Pray et al. 2001; Alpuerto et al. 2009; Gouse, Pray, and Schimmelpfennig 2004; Napasintuwong and Traxler 2009), and some have also examined the implications of the associated IPRs for social welfare (Falck-Zepeda, Traxler, and Nelson 2000a; Falck-Zepeda, Traxler, and Nelson 2000b; Giannakas 2002; Qaim and Janvry 2003; Qaim and Traxler 2005; Hareau, Mills, and Norton 2006; Hu et al. 2009; Pray, Govindasamy, and Courtmanche 2003). In general, these studies have shown that the countries where IPRs are enforced, such as in the United States, both producers (i.e. growers) and innovators received the bulk of the economic benefits resulting from biological innovations.

In this study, we extend the literature on the implications of IPRs for private research by considering the case of Herbicide tolerant (HT) rice in Brazil. This is the first study examining the welfare effects of a rice biotechnology in Brazil. HT rice in Brazil is a non-transgenic[1] (produced through mutagenesis) crop that was introduced in the country in 2004 under the name Clearfield (CR) by a multinational firm, BASF. It was introduced to control red rice[2], one of the most interfering weeds in the rice production system. CR varieties have an acetolactate synthase (ALS) enzyme resistant to herbicides from the imidazolinone (imi) chemical group used in weed management of red rice (Croughan 2003). The CR variety that was first introduced in the market is known as IRGA 422 CL. The other CR variety introduced more recently was Puitá INTA CL, which has replaced almost all the CR acreage since its introduction in 2009.

In Brazil, the southern state Rio Grande do Sul (RS) is the largest rice producer having average rice acreage and production around one million hectares and 5.3 million tons, respectively, over the last two decades. The rice production in RS rose over the years due to expansion in area, and investment in agricultural research to develop new varieties. The annual average growth rate in cultivated area in 1990-2010 was 2 percent, double the growth rate observed in yield. This means that not only improved varieties adapted to local environmental conditions, but also varieties resistant to herbicides used in weed control play a major role in boosting rice yield and quality. The rice sector in RS agrees that CR Rice has greatly contributed to red rice control with significant impacts on rice yields.

[1]There are three commercial HT rice technologies in the world; Clearfield, commercialized by BASF; Roundup Ready, commercialized by Monsanto; and Liberty Link, commercialized by Bayer CropScience. Clearfield rice is non-transgenic whereas Roundup ready and Liberty Link rice are transgenic (Rodenburg and Demont, 2009). It needs to mention that the transgenic HT rice was never commercialized in the Brazil. The transgenic Liberty Link rice was commercialized by Bayer CropScience in the U.S. in 2003 but it had never attained a significant market share because of worldwide rejection by rice consumers.

[2] Red rice is taller and more tillered than rice; each plant can produce up to 10 tillers and most seeds germinate early in the season. Prolonged dormancy is another critical weedy mechanism in red rice as their seeds can germinate even after 7 years in the soil.

Since the introduction of CR rice in Brazil in 2004, the acreage under Clearfield Rice rose to almost 55% in 2010. However, due to a weak Intellectual Property Rights (IPRs) structure in Brazil, nearly half of the CR Rice is illegally grown. Under the Plant Variety Protection Law (PVPL) in Brazil, producers are allowed to save seeds for future plantings, but are prohibited to save seeds to sell to other farmers without the innovator's consent. The general objective of this study is to examine the role of IPRs in affecting the welfare of producers and innovators in Brazilian rice market. The study is aimed to show whether the public nature of invention is managed by IPR exclusion mechanisms and therefore whether the supplier of technology is able to earn economic rents. From a social welfare perspective, this study shows whether there are plausible grounds for a change in IPR enforcement and its potential effects on welfare of interest groups. Pray et al (2003) argued that a favourable economic environment is required for firms to invest in biotech research. This study analyses whether such environment exists for the case of Clearfield Rice in Brazil. The specific objectives of this study are: (1) to estimate the change in welfare of rice producers and innovators in Brazil after the introduction of CR rice, (2) to simulate changes in welfare in the presence of stronger IPRs structure

The paper is organized as follows. The next section presents the conceptual model and methods used in this study. Information on data and parameters used in the model is presented in the succeeding section. The results of the analysis are then discussed, and the final section makes concluding remarks and discusses some limitations.

Methodology

Economic surplus model by Alston, Norton and Pardey (1995) was employed to estimate the economic impact of HT rice on producers and consumers of rice. To account for benefits realized by the technology supplier on IPR-protected CR, the extended version of Moschini and Lapan (1997) framework was used. Brazil is assumed as a small open economy in the economic surplus model as it is not a large rice trader and thus cannot affect the world price of rice. CR Rice, the rice tolerant to the imi-herbicide used in red rice control, is assumed to confer a yield and cost advantage in comparison to conventional rice. Figure 1 shows the conceptual model of Brazilian rice market illustrating the change in economic surplus resulting from adoption of CR rice in Brazil.

The initial equilibrium is characterized by the levels of consumption C_0 and production Q_0 of rice that occur at the world price P_w. The difference between production and consumption, i.e., QT_0 is exported. With adoption of CR technology, supply curve for rice shifts rightward from S_0 to S_1 and production of rice is expanded to Q_1. Greater rice production in Brazil leads to an increase in exports to QT_1. The surplus change is equal to area I_0abI_1, which can be calculated using the following equation.

$$\Delta PS_t = \Delta TS_t = P_R Q_t K_t (1 + 0.5 K_t \varepsilon_R) \qquad (1)$$

where P_R is the price of rice in Rio Grande do Sul (RS), and Q_t is the quantity of rice produced in RS prior to CR technology introduction. A single market price for rice reflecting a homogeneous market is assumed in the analysis; because it is hard to differentiate between CR and conventional rice once it enters the processing chain. K_t is the major parameter in equation (1), which is also referred to as a supply shifter. K_t is calculated by solving the following equation.

$$K_t = \left[\frac{E(Y)}{\varepsilon_R} - \frac{E(C)}{1+E(Y)} \right] \rho A_t (1 - \delta_t) \qquad (2)$$

where $E(Y)$[3] is the expected proportionate yield change per hectare in period t due to adoption of CR, $E(C)$ is the proportionate change in input cost per hectare to achieve the yield change, ρ is the probability that CR will achieve the expected yield, δ_t is the technology depreciation factor and A_t is the adoption rate at time t, starting from year 2004 when CR technology was commercially available in Brazil.

In order to account for economic rents accruing to the innovating firm operating in an environment where IPRs are in place, we used a method by Hareau, Mills and Norton (2006) which is an extension to the framework developed by Moschini and Lapan (1997). The method calculates the monopoly profits as follows.

[3] To empirically estimate *E(Y)*, rice yield in Brazil is estimated as a function of several factors including an indicator on Clearfield Rice. Estimations in both cross-sectional as well as time-series regression settings were made; the results of which are shown in Appendix 1.

$$\pi_t = \mu_t A_t L_t \qquad (3)$$

where μ_t is the technology fee charged per hectare, A_t is the adoption rate of technology and L_t is the corresponding crop area.

Data and Parameters

Area, production and price data for Rice in RS, Brazil from 2005-2009 were collected from IRGA (Instituto Rio Grandense do Arroz) as shown in Table 1. Average area, production, and price of rice were 1.039 million ha, 7.147 million tonnes, and R$ 25.66/50 Kg bag, respectively. The data on adoption of CR (including illegal farm-saved seeds) from 2004-2010 were provided by BASF, according to which it is estimated that 50 percent of CR adoption is under certified seeds and the remainder is under farm-saved seeds. Technology was assumed to be depreciating at a rate of 2 percent from 2004-2010, and 4 percent in succeeding years in order to account for natural weed resistance over time. Average rice price and quantity in 2005-2010 were collected from the Food and Agricultural Organizations of United Nations (FAO) and Center for Advanced Studies on Applied Economics (CEPEA). Long run supply and demand elasticities for rice in Brazil were assumed to be 0.44 and -0.90, respectively (Cap et al. 2006). As the CR technology is already commercialized in Brazil, the probability of success of the technology is assumed as one ($\rho = 1$). Since BASF expects that CR becomes obsolete in 20 years after its introduction[4] in 2004, an annual rate of disadoption is considered to take a logistic path which is assumed to begin in year 2013, and approaches zero in year 2023.

Based on the estimations in Appendix 1, the yield gains achieved with CR adoption suggested by the two empirical models are 15-30 percent. Discussions with farmers and input suppliers revealed that 30 percent may be too high, although it would be achievable by large scale farmers with high level of technology – which according to IRGA are concentrated in the Fronteira Oeste region (IRGA 2005). Thus, the yield improvement due to CR adoption is assumed 15 percent for the baseline scenario. Sensitivity analysis is conducted for a scenario of 20 percent yield improvement in order to obtain an upper bound estimate of change in surplus.

[4] Verbal communication with BASF's Clearfield managers (August 2011).

Table 2 illustrates the major cost components considered by IRGA to estimate the cost per bag of rice. In addition, we also used the cost data compiled by Kleffmann (Table 4) to substantiate the cost difference between CR and conventional rice obtained from IRGA's data. Discussions with IRGA's agronomists revealed that farm operations to grow CR and conventional rice are considered virtually the same, except for type of seeds and weed management systems. The difference in weed and pest management cost (row 7) for CR and conventional rice reflects solely the herbicide cost, because pesticide use is considered identical for CR and conventional rice. The seed costs incurred by farmers that grow CR illegally are significantly lower in comparison to the costs of certified seeds because royalty fees are not paid by those farmers. Generally, farmers that employ farm-saved CR seeds either grow their own seeds or purchase seeds from other farmers. The seed costs under these two scenarios are different as shown in Table 3. If a farmer grows his own seeds, seed costs are estimated to be 1.25 times the market price of rice[5] ($59.10 per hectare). Although the cost of farm-saved seeds is 46 percent lower than the cost of certified CR seeds, the cost difference is not large when overall variable costs are considered. This is because seed costs account for an insignificant share (3.48 percent) of overall variable costs. Similarly, if the farmer purchases CR farm-saved seeds marketed in bags of 50 kilos[6], per hectare cost of CR would be $73.10, which is 33 percent lower than purchased certified seeds, or equivalently, 4.27 percent of total average cost of production. Among the farmers using farm-saved seeds, it is estimated that 30 percent of the farmers use self-produced seeds, and the remaining 70 percent purchases seeds produced by other farmers. Thus the surplus estimations, which are conducted separately for farm-saved and official CR adoption, take into account the cost reductions and their respective percentage shares.

The herbicides/fungicides costs difference in Table 4 (row 10) is all attributable to herbicides. Thus the total cost change as a result of CR adoption is -0.71 percent, which mirrors the findings in Table 2 (-0.41 percent). On the basis of these results a one percent change in cost was assumed in the surplus analysis.

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[5] Verbal communication with IRGA's agronomists and BASF members.

Results

Per-hectare mean yields by different farm sizes and sowing operations are shown in Table 5. In farms smaller than 200 hectares, the mean yield of CR was 9.66 tons per hectare versus 9.08 tons per hectare for conventional rice. Difference in yields of CR and conventional rice is more pronounced in medium and large farms. The yield was 10.50 tons per hectare for CR rice in comparison to 8.28 tons per hectare for conventional rice, on the medium farms. On the large farms (> 1000 hectares), yields of CR and conventional varieties were 13.37 and 10.00 tons per hectare, respectively. An overall higher yield in large farms is an indication of scale economies.

Small farmers growing conventional rice are likely to yield higher than medium farms (9.08 versus 8.28 tons per hectare), possibly because they assimilate high performance techniques more consistently (Feder, Just, and Zilberman 1985). Point estimates of yield in farms where no tillage was chosen over other sowing practices such as semi-tillage and conventional tillage suggest that higher yields may be associated with environmentally friendly practices, given no tillage is less machinery intensive. CR rice with no-tillage yielded 12.52 tons per hectare, which is higher than CR plots with semi-tillage and conventional tillage yielding 9.09 and 10.2 tons per hectare, respectively.

T-tests were conducted to investigate whether the apparent differences in yields among different categories of farms are statistically significant (Table 6). The mean yield between CR and conventional rice is not statistically different for small and large farmers, which means that CR planted in farms smaller than 200 hectares does not necessarily yield higher than conventional rice planted on small farms. A similar relationship holds among large farmers where it does not appear to be a statistically significant difference between the CR and conventional rice. In medium farms, which are the largest group of households in the sample (61 percent of conventional and 53 percent of CR growers), average yield of CR was found to be statistically different from average yield of conventional rice.

Table 7 shows the net present value (NPV) of changes in producer surplus, BASF surplus and total surplus for the rice sector in Brazil after the introduction of CR rice technology. The NPVs were calculated with a 12 percent discount rate (BACEN 2011) on annual surplus estimates based on the assumptions that in each year half of the CR acreage is planted to official seeds purchased from BASF's certified breeders, and the other half is planted to farm-saved seeds. Further from the farm-saved seeds, 30 percent were produced by the own farmer and 70 percent were purchased from illegal breeders.

The time frame for surplus calculation in Table 7 is from year 2009 to 2018. From 2004-2008, the royalty fees charged by BASF were a percentage share on the price of seed bag. The company was not able to collect the revenue its technology fee would have been generated in this period. Since an estimate of the technology revenue for 2004-2008 was not available, the total surplus for this period may be underestimated. In 2009, BASF replaced its percentage share pricing with a fixed royalty fee pricing. In 2010, the royalty fee was raised by 39 percent, which was assumed to be constant in subsequent years.

The two CR varieties examined were IRGA 422 CL and Puitá INTA CL. Puitá INTA CL has accounted for almost all the CR acreage since its introduction in 2009. Research and development costs were assumed as sunk costs and were not considered in the surplus analysis. BASF estimates that the total costs to adapt the Clearfield technology into rice varieties in Brazil and to release the new varieties in the local market were only $1.15 million.

Under the baseline scenario, the NPV of total surplus benefits that are expected to be created by CR technology amounted $20.7 billion over a time period ranging from 2009 to 2018. The largest share of these benefits (69.5 %) was realized by CR farmers; BASF captured 30.5 percent of the total benefits. Therefore, the notion that royalty fees allow firms to make far more profit than the economic gains received by producers is not supported by the findings of this study. The significant gains to producers were due to the cost reduction (although discrete) and the yield advantage of CR technology. In a similar context, Hareau, Mills and Norton (2006) found that 76.6 percent of the NPV of total surplus change from GM rice in Uruguay went to producers and the remainder 23.4 percent went to the innovator. The magnitude of the benefits, however, was lower due to relatively lower acreage under rice in Uruguay. The area under rice in Uruguay was about one sixth of the total rice acreage in RS.

The results in Table 8 show how the welfare distribution would change when enforcement of the PVPL eliminates the 70 percent of farm-saved seeds that were illegally marketed to farmers. The results show welfare effects in the small open economy context when all farmers grow certified seeds from BASF, with the exception of the 30 percent of farm-saved seeds used for replanting. The results indicated that the NPV of the surplus increment that would be realized by farmers from 2009-2018 summed \$26.4 billion, which is almost twice as much the benefits they earned under the current IPR regime. The innovator i.e., BASF is also likely to increase its revenue from royalty fees since all farmers willing to grow CR would have no alternative other than purchasing certified seeds. NPV of the surplus captured by BASF is likely to be more than double of the surplus benefits under baseline. Nevertheless, the distribution of benefits is not drastically reversed. From 2009 to 2018, producers are expected to realize on average 67.6 percent of total welfare, while BASF's average share is likely to be 32.4 percent of total welfare, under no IPR infringement. Thus under complete IPR enforcement, producers almost double their benefits and collect the largest share of the total welfare to society (67.6 percent). Hence, the generalized notion that a policy change leading to a strict IPR system would reverse the order of the main beneficiaries and cause an imbalance from a social welfare perspective is not endorsed by the results from this exercise. The results are in congruence with Hu et al. (2009) who found that cotton farmers received the largest share of surplus benefits created by Bt cotton under an IPR reform in China.

Sensitivity analyses were also conducted by assuming an increase in rice yield by 20 percent as a result of CR adoption. The benefits from a higher yield increase are primarily captured by producers. Producers are likely to further expand their share of total welfare to 74.8 percent from the baseline value of 69.5 percent (Table 7). BASF's profits are kept constant in the event of a 20 percent yield increase as we assume that farmers will not respond to a greater yield impact of CR by increasing demand for CR. Total welfare changes under the baseline scenario and greater yield scenario are presented in Figure 2.

Furthermore, either yield increase or avoiding yield losses is affected by production choices made by producers. In practice, the spread of CR farm-saved seeds intensifies the pace of technology depreciation. Farmers that resort to saved seeds usually do not follow the stewardship guidelines that are aimed to minimize the risk of outcrossing and occurrence of red rice resistance to imi-herbicides. This suggests that technology depreciation could be retarded by adoption of certified CR seeds in combination with recommended agronomic practices. Thus producers would ultimately benefit from a "slower" rate of depreciation in a similar fashion they would gain from greater CR yield advantage.

The question that arises is why there is a significant adoption of farm-saved seeds if the benefit from higher yields more than offsets the cost of the technology fee charged for CR certified seeds? At first, the technology provider may have not anticipated the high demand for CR seeds in the first year or two after the release and did not allocate enough seeds for breeding. As a result, even those farmers willing to purchase certified CR seeds would have to resort to seed material that had been saved by other farmers. Whether this hypothetical seed shortage is actually part of the picture remains to be verified. It is widely felt that companies typically forecast demand for seeds based on seed replacement rate (SRR), i.e., the share of total acreage planted to certified seeds. Therefore, it is unlikely that there were not enough seeds in the market, especially after the first year.

The price of farm-saved seed does not include royalty fees since it was not produced by one of BASF's licensed seed suppliers. Rice producers may think that IPR infringement is profitable on the grounds that the cost of technology fee is avoided. However, the cost sensitivity analysis shows that farmers may not be acting as rational economic agents by choosing to violate IPRs. As discussed before, farm-saved seeds are expected to bring lower gains to producers because they do not have the same yield potential and the ability to control red rice as that of certified seeds. More importantly, the cost advantage of using saved seeds over conventional rice is insignificantly higher than the cost advantage of CR seeds (more expensive due to royalty fees) over conventional rice. Farmers may grow their own seeds where the cost of seeds is estimated at 1.25 times the market price of rice or they can purchase saved seeds from other farmers. If a farmer cultivated its own seeds, a bag of seeds would cost him USD 59.10/ha, lowering variable cost per hectare by 3.23 percent relative to conventional rice. On the other hand, if a farmer purchased saved seeds, which are marketed in bags of 50 kilos, a seed bag would cost him USD73.10/ha and variable cost per hectare is 2.43 percent lower than conventional rice. Figure 3 plots the NPV of surplus benefits to producers resulting from adoption of CR technology under different adoption settings.

The plot depicts amount of economic benefits on the vertical axis, and seed costs on horizontal axis. The size of the bubble is proportional to the yield improvement due to CR adoption. Combinations that are further up and to the right of the origin (north-eastern) are preferable. Figure 3 illustrates that the farmers would be better off in terms of earning greater economic surplus if growing certified CR. Although it has somewhat higher seed costs; the yield difference and surplus benefits are significantly higher.

Conclusions

The study concludes that with complete IPR enforcement both economic agents, i.e. producers and innovators would benefit, which may support a government proposal towards greater enforcement of the PVPL. The producers would continue to collect the largest share of total welfare to society under stricter IPRs regulations. Hence, the generalized notion that a policy change leading to a strict IPR system would reverse the order of the main beneficiaries and cause an imbalance from a social welfare perspective is not endorsed by the results from this exercise. This ramification is meaningful to policy makers in developing countries whose role is to stand by the projects that are likely to produce sizeable benefits to society, and at the same time creating a favourable economic environment for multinationals to introduce products of their research. The partitioning of benefits under IPR enforcement is more likely to create the economic environment that would be considered adequate to conducting privately funded research. Therefore, higher expected gains with a new technology will likely make private firms more inclined to conduct research in the long run.

We believe that a definitive statement on this direction may require more complete farm-level data that would allow a categorical estimation of yield and cost change of Clearfield versus conventional rice. Also the study did not investigate the response of private investment to the IPR provisions and it was assumed that research and development costs were sunk costs. IPR enforcement and monitoring costs are also not considered in the analysis, which may have an impact on welfare to society.

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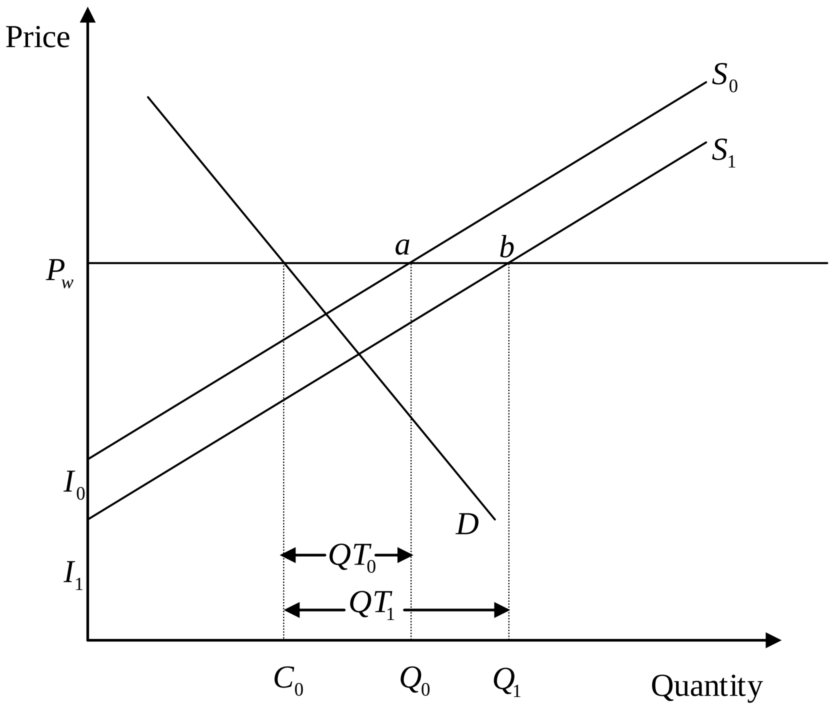

Figure 1. Economic surplus from Clearfield Rice introduction in Brazil.

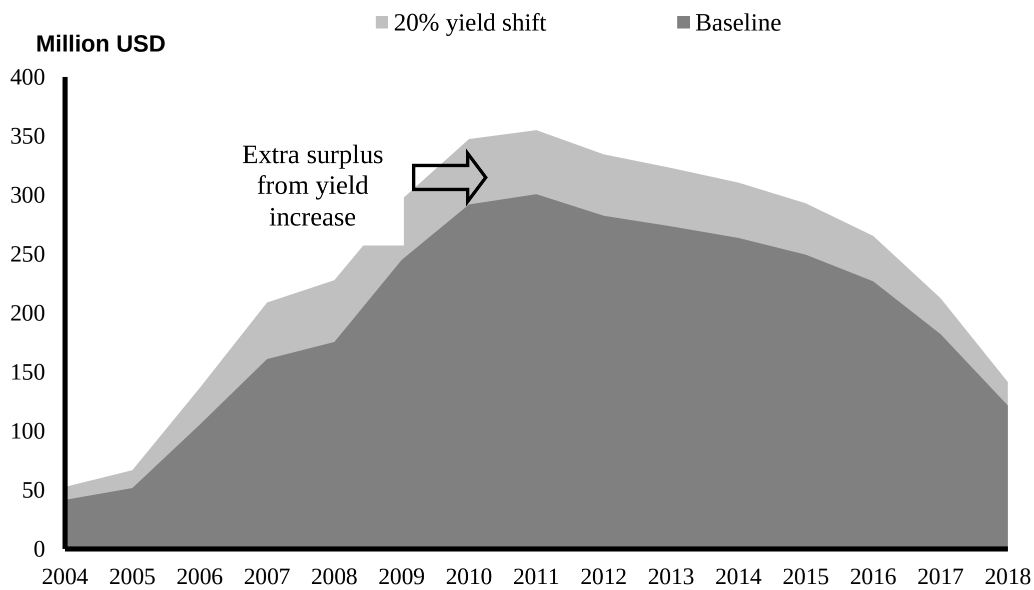

Figure 2. Surplus increment with higher yield increase (million USD).

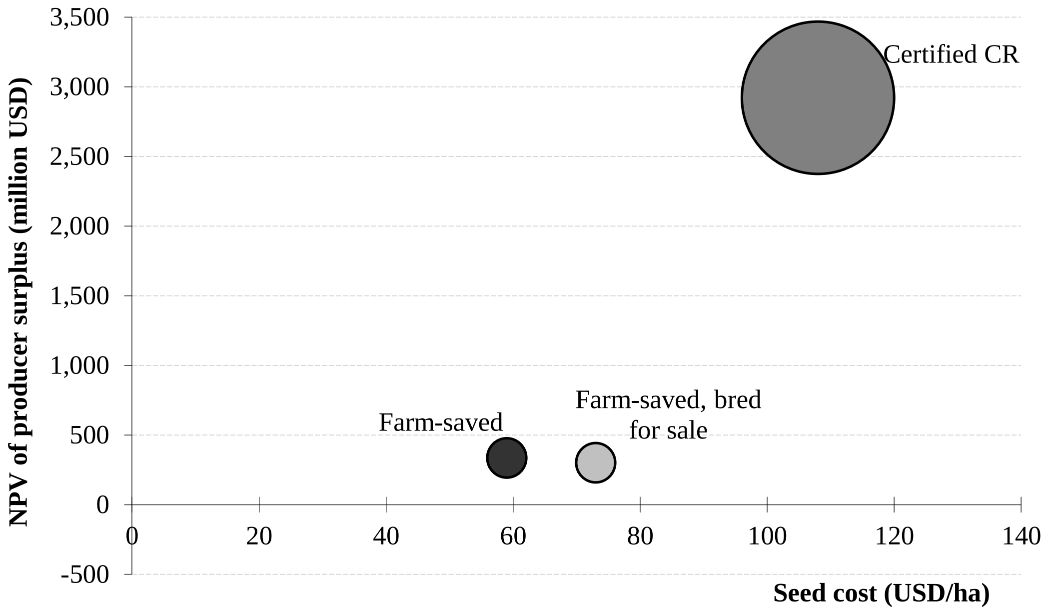

Figure 3. Surplus, yield and cost change comparison for certified and farm-saved CR.

Table 1. Area, production and price of rice in RS.

Year	Area (1000 ha)	Production (1000MT)	Price (R$/50 kilo bag)
2005/06	1,029	6,861	20.16
2006/07	941	6,494	21.63
2007/08	1,067	7,535	31.04
2008/09	1,105	8,048	28.05
2009/10	1,053	6,799	27.42
Average 06-10	1,039	7,147	25.66

Source: (IRGA; CEPEA)

Table 2. Costs of production of CR and non-CR, 2010

	Conventional		Clearfield	
	USD/ha	Cost share (%)	USD/ha	Cost share (%)
1. Soil preparation	230.28	13.11	230.28	13.17
2. Soil drainage	64.16	3.65	64.16	3.67
3. NPK / Top dressing	229.77	13.09	229.77	13.14
4. Seeds	94.83	5.40	108.62	6.21
5. NPK / Top dressing application and Sowing operations	68.33	3.89	68.33	3.91
6. Irrigation	327.48	18.65	327.48	18.73
7. Weed and pest management	169.71	9.66	148.81	8.51
8. Harvest	241.26	13.74	241.26	13.80
9. Inner farm transportation	51.44	2.93	51.44	2.94
10. Freight	132.01	7.52	132.01	7.55
11. Rice drying	146.70	8.35	146.70	8.39
12. Total variable cost	1,755.96	100	1,748.85	100
13. Cost change (%)			-0.41	

Source: IRGA, CR seed cost from BASF

Table 3. CR seed costs.

	Seed cost (USD/bag)	Seed cost share in total variable cost (%)
Certified CR	108.62	6.21
Farm-saved	59.10	3.48
Farm-saved marketed	73.10	4.27

Source: (IRGA and BASF)

Table 4. Costs of production of CR and non-CR, 2010.

		Conventional		Clearfield	
		Mean	Std. Dev.	Mean	Std. Dev.
1.	Seed cost (USD/ha)	75.04	10	86.72	11
2.	Labor				
3.	Land preparation (hrs/ha)	5.11	2	5.23	2
4.	Weeding (hrs/ha)	0.25	0	0.44	0
5.	Herbicide application (hrs/ha)	0.44	0	0.42	0.27
6.	Inseticide / fungicide application (hrs/ha)	0.45	0	0.49	0
7.	Total labor	6.25	-	6.58	-
8.	NPK fertilization (USD/ha)	190.94	150	188.63	170
9.	Top dressing fertilization (USD/ha)	134.85	94	130.44	87
10.	Herbicides / Pesticides (USD/ha)	132.60	103	123.18	105
11.	Cost change (%)			-0.71	

Source: Kleffmann (2010)

Table 5. Yields by farm size and sowing practice (ton/ha) [Kleffmann survey, 2010]

	Conventional rice			Clearfield rice		
	Mean (1)	Std. Dev (2)	Number of observ.[a]	Mean (3)	Std. Dev (4)	Number of observ[a]
1. Small farm	9.08	5.67	88	9.66	5.66	101
2. Medium farm	8.28	5.80	212	10.50	6.75	132
3. Large farm	10.05	6.96	47	13.37	7.67	18
4. Semi-tillage	8.74	5.89	255	10.20	6.61	187
5. No-tillage	7.89	5.09	41	12.52	6.55	34
6. Conventional tillage	6.28	4.57	14	9.09	4.30	21

[a]Pre-germinated seeds and transplanted seeds are omitted due to their small number of plots.

Table 6. Two sample t-tests of selected hypotheses.

		two sample t-test	p value (alpha level .05)
	Hypothesis 1:		
	Conv. yield versus CR yield by farm size		
1.	Small farm	t (187) = -0.7001	0.4847
2.	Medium farm	t (342) = -3.2353	0.0013***
3.	Large farm	t (63) = -1.6745	0.0990
	Hypothesis 2:		
	Large farm yield versus other farm sizes' yield		
4.	Clearfied rice	t (249) = -2.0659	0.0399*
5.	Conventional rice	t (345) = -1.6435	0.1012
	Hypothesis 3:		
6.	Conv. yield no-tillage versus CR yield no-tillage	t (73) = -3.4411	0.001***
	Hypothesis 4:		
	No-tillage yield versus other operations' yield		
7.	Clearfield rice	t (249) = -2.1117	0.0357*
8.	Conventional rice	t (345) = 0.9508	0.3424

* significant at 5 percent level. ** significant at 1 percent level. *** significant at 0.5 percent level.

Table 7. NPV of change in surplus (million USD).

Producers' surplus ($)	14,412
Technology revenue ($)	6,315
Total surplus ($)	20,727
Producers (%)	69.5
BASF (%)	30.5

Table 8. Sensitivity results for IPR enforcement (NPV, million USD).

Producers' surplus ($)	26,398
Technology revenue ($)	12,631
Total surplus ($)	39,028
Producers (%)	67.6
BASF (%)	32.4

Table 9. Sensitivity results for yield change (NPV, million USD).

	Baseline (ΔY=15%)	Sensitivity (ΔY=20%)
Producers' surplus ($)	14,412	18,712
Technology revenue ($)	6,315	6,315
Total surplus ($)	20,727	25,027
Producers (%)	69.5	74.8
BASF (%)	30.5	25.2

Appendix 1: Rice yield models estimations in Brazil

To empirically estimate the E(Y), log of yield is estimated as a function of several factors including the dummy representing the type of rice. The model is specifed as follows:

$$Ln(Yield) = f(CR, Age, Educ, GeoArea, FarmSize, Tillage) \qquad \text{A1.1}$$

where *CR* is a dummy variable with a value equal to one if farmer grows CR Rice (either IRGA 422 CL or Puitá INTA CL), and 0 if he grows conventional varieties. We are basically interested in an estimate of coefficient of '*CR*' after controlling for other factors. '*Age*' is a categorical variable representing different categories of age of farmers. '*Educ*' is the education level (years of education) reported by the household head. '*GeoArea*' is a categorical variable classifying different regions in study area. '*FarmSize*' is a categorical variable for farm size. '*Tillage*' is a dummy variable for the tillage system employed by farmers. The model in equation A1.1 is estimated using the farm-level survey data collected by a market research company, i.e., Kleffmann, during the 2009/2010 rice season in southern Brazil.

The Ordinary Least Squares (OLS) estimators derived from the first model using the cross sectional data are illustrated in AT1.1. Alternative regression forms were tested to evaluate the potential effect on the coefficient explaining expected increase in yield of rice after adoption of CR technology. The coefficients on the CR variety are found to be positive and significant in all regression specifications, which imply that CR yielded higher than conventional rice. Other variables held constant, CR varieties (i.e., IRGA 422 CL or Puitá INTA CL) allowed farmers to increase yield by 18 percent on average (significant at 1 percent in regressions 1-3). However, the yield is likely to increase by 15.6 percent due to CR technology as shown in regression 4, which is significant at 5 percent level.

Findings suggested a 15-18 percent higher yield for CR in comparison to conventional rice varieties. These results are similar to a 9-12 percent yield gain due to GM HT rice adoption, estimated by Huang et al. (2008). Fuller et al (2003) and Annou et al (2005) reported a yield increase of rice between 1-20% (depending on level of red rice infestation) due to HT rice adoption. Hareau, Mills and Norton (2006) assumed stochastic parameters of 0, 2.5 and 5 percent yield increase in their ex ante impact analysis for rice in Uruguay; their assumptions were based on Oard et al. (1996) who estimated a 7 percent yield increase from HT rice adoption.

The explanatory power of the analysis (i.e. R^2 or coefficient of determination) for regression models was lower than the value (of 0.3) considered standard for farm-level data analysis (Hu et al. 2006). Against this backdrop, a time-series econometric model for yield response in RS was estimated using time-series data on rice production in RS during 1994-2010. The model is presented as:

$$Ln(Yield_t) = f(AdopCR_t, RF_t, Temp_t, t) \qquad \text{A1.2}$$

where '$AdopCR_t$' is the adoption rate of conventional rice. To account for the observations before 2004 (when CR was introduced in Brazil), we include in the model adoption rate of conventional rice instead of adoption rate of Clearfield rice. 'RF_t' is the average local rainfall reported by the National Water Agency of Brazil's Ministry of Environment. '$Temp_t$' is the average annual temperature in RS measured by the GISS Temperature Analysis of NASA (National Aeronautics and Space Administration). 't' is the time trend.

The Ordinary Least Squares (OLS) estimates from the model are illustrated in Table AT1.2. The model has relatively high explanatory power, with adjusted R^2 between 0.79 and 0.71. Table AT1.2 shows that the coefficient on adoption seems to be biased upward when the time trend is omitted (column 1). The coefficient of interest is that of CR adoption, which is derived from a transformation of conventional rice adoption[7].When the time trend is not included in the regression (column 1), the coefficient on conventional adoption is -0.666 which is significant at 1 percent, and the CR adoption impact seems overestimated at 50 percent i.e., CR yields twice as much as conventional rice (which is unlikely to conceive). The coefficient on conventional adoption drops to 0.359 when the time trend is considered. As a result, the coefficient on CR adoption also falls to 0.302, which implies a 30 percent higher yield of CR rice in comparison to conventional rice (considered high but somewhat acceptable in practice).

[7] The percentage effect of CR adoption on yield (β_1'), holding other factors constant, is given by the following algebraic transformation of the coefficient on conventional adoption (α_1): $\beta_1' = (e^{\alpha_1} - 1) \times 100$.

AT1.1. Regression results for rice yields in RS.

	Yields (ton/ha) in Log			
	(1)	(2)	(3)	(4)
1. CR dummy	0.181	0.181	0.178	0.156
	(2.96)**	(2.95)**	(2.90)**	(2.48)*
Household characteristics				
2. *Education (years)*	0.007	0.007		0.007
	-1.43	-1.66		-1.54
Age				
3. *up to 30 years old,*	0.071		0.08	0.074
young	-0.81		-0.91	-0.85
4. *older than 60 years old,*	-0.022		-0.04	-0.027
senior	-0.35		-0.64	-0.43
Regional effects				
5. *Capital area RS*	0.047	0.047	0.028	0.05
	-0.5	-0.5	-0.3	-0.53
6. *Southwest RS*	-0.186	-0.185	-0.165	-0.192
	(2.32)*	(2.33)*	(2.09)*	(2.41)*
7. *Mid-west RS*	-0.285	-0.279	-0.278	-0.284
	(2.18)*	(2.14)*	(2.13)*	(2.18)*
8. *Mid-east RS*	-0.069	-0.066	-0.042	-0.063
	-0.52	-0.5	-0.32	-0.47
Farm size				
9. *Mid-size farms (200-1000ha)*	-0.079	-0.074	-0.072	-0.072
	-1.21	-1.14	-1.11	-1.11
10. *Large farms (>1000ha)*	0.106	0.116	0.123	0.115
	-1.04	-1.14	-1.22	-1.13
Sowing operations				
11. *Semi-tillage*	-0.078	-0.085	-0.06	-0.079
	-0.91	-0.99	-0.7	-0.92
12. *Conventional tillage*	-0.303	-0.31	-0.281	-0.547
	(2.16)*	(2.22)*	(2.01)*	(2.75)**
13. *Pre-germinated seeds*	-0.024	-0.028	-0.006	-0.035
	-0.18	-0.21	-0.04	-0.25
14. *Transplanted seeds*	-0.239	-0.266	-0.199	-0.214
	-0.35	-0.4	-0.29	-0.32
15. Conventional tillage x CR				0.412
				-1.73
16. Observations	597	597	598	597

Absolute value of t statistics in parentheses.
* significant at 5%; ** significant at 1%.

AT1.2. Estimated parameters with time trend included.

	Yields (ton/ha) in Logs	
	(1)	(2)
1. Conventional rice adoption	-0.666	-0.359
	(5.47)**	(2.22)*
2. CR adoption[a]	0.486	0.302
3. Rainfall (mm/year)	-0.001	-0.001
	-1.65	(2.37)*
4. Temperature (ºC/year)	0.087	0.055
	-1.71	-1.21
5. Time trend		0.017
		(2.46)*
6. Adj. R-squared	0.71	0.79

Absolute value of t statistics in parentheses

* significant at 5%; ** significant at 1%

[a]CR adoption coefficient calculated by $\beta_{CR} = \left(1 - e^{\beta_{CV}}\right)$.