Environment and Development Economics 8: 187–205 © 2003 Cambridge University Press
DOI:10.1017/S1355770X0300010X Printed in the United Kingdom

Potential economic impacts of terminator technologies: policy implications for developing countries

C.S. SRINIVASAN
Department of Agricultural and Food Economics, University of Reading, Reading, RG6 6AR

COLIN THIRTLE
Department of Environmental Science and Technology, Imperial College of Science, Technology and Medicine, RSM Building, Prince Consort Road, London SW7 2BP

ABSTRACT. The terminator gene can render seeds sterile, so forcing farmers to purchase fresh seed every year. It is a technological solution to the problem of market failure that could increase the appropriability of R&D investment more effectively than intellectual property rights legislation or patents. This paper shows that appropriability should be more than tripled and that this leads to greater private R&D investment, which may be expected to double or triple. This would bring open-pollinating varieties into line with F1 hybrids, for which seed cannot be saved. In turn, the increased investment should raise yield increases to levels similar to those for hybrid crops. Thus, there are benefits to set against the possible ecological and environmental costs and the clear distributional and social consequences. The paper discusses the way the seed market is developing, the possible impacts, especially from a developing country viewpoint, and considers the policy changes that are needed.

1. Introduction

The emerging technology for inducing sterility in seeds, which has popularly come to be known as terminator technology or genetic use restriction technologies (GURTs) has the potential to bring far-reaching changes in the seed industry and the organization of agriculture. Terminator technology alters a fundamental characteristic of seed—its self-reproducing nature—and threatens to change agricultural practices that have been the norm for centuries. Seldom does an innovation have the potential to alter a production process in such a fundamental way. Given its potential impact, it is understandable that terminator technology has attracted a virulent and

This paper was presented at a workshop on the management of the impacts of biotechnologies, entitled 'Biotechnology, Environmental Policy and Agriculture', sponsored by the European Science Foundation and the UK Department of International Development, 28–30 May 2000, Rome, Italy. We thank the workshop participants and two anonymous referees for helpful comments.

https://doi.org/10.1017/S1355770X0300010X Published online by Cambridge University Press

polemical response from a range of quarters. It has been seen as an unethical or immoral technology that threatens the livelihood of millions of farmers, especially resource-poor farmers in developing countries. It is viewed as a technology that needs to be stopped in its tracks, or discarded completely, if its adverse consequences are to be avoided. This response has discouraged a more dispassionate economic analysis of the technology, which must attempt to identify the economic forces that have induced the development of this technology. There may be insights to be gained in viewing terminator as an induced technological response to the inadequacies and weaknesses of existing intellectual property rights (IPR) institutions. The technology has important consequences for the implementation, enforcement, and duration of intellectual property rights for plant varieties. Consequently, the technology could have a significant impact on the appropriability of returns to investment in plant breeding and the level of investment in the development of new plant varieties. The potential impact on innovation in the plant-breeding sector must be taken into account when the balance sheet for the technology is drawn up. The current intense debate about the technology has obscured the fact that the choice for developing countries may not simply lie in accepting or rejecting the technology altogether. Other strategic responses, involving the regulation of the application of the technology may be available and need to be explored.

2. Terminator technology

The complex biotechnological processes involved in terminator technology are not readily accessible to non-specialists. The details of how these processes work are contained in lengthy technical patent documents, quite difficult to comprehend even for someone skilled in the art. Ironically, while seed multinationals have been severely criticized in their attempts to promote the technology, the origin of the controversy can be traced to a patent granted jointly to the United States Department of Agriculture and the Delta & Pineland Company in 1996. The technology involves the following components:

1. Techniques for development of seeds that grow normally when first planted by farmers, but which produce sterile seeds at the end of the cycle, i.e. on harvest.
2. Techniques, which allow companies to produce seed for sale to farmers that grow normally.
3. Techniques that ensure that other product characteristics remain unaffected. This implies that terminator technology should come into play at a late stage in seed development.

From the economic point of view, the most important implication of this technology is that farmers cannot save seeds from their crops: they have to buy fresh seeds from the seed companies every year. The technology is relevant only for self- or open-pollinated varieties, since for hybrids, farmers generally buy seed every year because of the loss in yield (owing to the loss of hybrid vigour) when second generation seeds (F2) are used. Thus, there is no incentive for seed companies to put terminator technology into hybrid varieties, as there is already a mechanism to ensure repeat pur-

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chases of seed by farmers. However, a review of the terminator literature shows that the development of the technology is not oriented only toward seed sterility. The same technology can be used to switch on or off specific traits in the seeds of a variety. Particular traits can be rendered dormant and may be expressed only when the seeds are used in conjunction with proprietary chemicals. Thus, the technology opens up new possibilities for companies to bundle together seeds and other inputs.

It is not clear in which crop species the implementation of terminator technology will ultimately prove feasible. However, if terminator emerges as a truly generic technology, capable of being implemented in a whole range of crops species and varieties, then it may become the biotechnologist's vehicle of choice for the delivery of innovations. All biotechnological innovations (e.g. transgenic varieties resistant to insects) would be delivered to the market bundled with terminator. Even the availability of existing varieties could be affected if companies choose to sell them only in the terminator version.

Unlike genetically modified varieties that offer agronomic benefits to farmers, terminator technology offers only economic benefits to seed companies. This paper explores the economic rationale for its emergence. The next section reviews the relationship between IPRs and the appropriability of returns to R&D. The fourth section presents a model of appropriability for new plant varieties and section 5 investigates the effect of appropriability on the level of private R&D expenditures. Section 6 considers the potential impacts of terminator technology, especially from a developing country viewpoint and the final section concludes the paper.

3. Plant breeding, intellectual property rights and the appropriability of the returns to R&D

It is generally recognized that the growth of agricultural production has become critically dependent on yield increases primarily based on the development of new high-yielding varieties. While traditionally, the development of new varieties was the result of informal innovation by farmers over several generations, in the last 125 years this process has been greatly accelerated by scientific plant breeding, which has emerged as one of the most important areas of agricultural research. Its distinguishing feature is the *planned incorporation* of specific desirable traits in new varieties using the range of *techniques* and *information* available to plant breeders (OECD, 1993). Modern plant breeding not only takes place in a different institutional context, but this process of evolving new varieties is fundamentally different from the farmer's process that relies on careful selection from randomly occurring mutations in nature.

The transformation of plant breeding into an organized scientific activity raises two questions on incentives for research. First, whether any form of intellectual property rights can be made applicable to plant breeding, and, second, whether the market mechanism will produce an optimal level of investment in plant breeding.

In the case of industrial products the concept of intellectual property rights (IPRs) as a device for promoting innovation has been around for more

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than 500 years (Machlup, 1958). The Paris Convention for the protection of industrial property dates back to 1860. But the idea of applying IPRs to plant varieties took another hundred years to emerge. An important reason for this was that, until recently, the prevailing paradigms of IPRs precluded their application to living materials. However, the most important difficulty in applying IPRs to plant varieties arose from the difficulties in segregating and appropriating benefits from their use (Swanson, 1997).[1] This difficulty arose directly from the self-reproducing nature of seed. Once a plant breeder released a new variety to farmers through the sale of seed, he had no further control over the use of the variety, as farmers could multiply it themselves. The benefits that the breeder could appropriate by the direct use of his new variety would be only a very small fraction of the total social benefit that could be derived if his variety were to be widely diffused to farmers. The vast discrepancy between the benefits that could be appropriated privately by the breeder and the total social benefits implied that the market mechanism would fail to produce a socially desirable level of investment or effort in plant breeding. Thus, the market mechanism would invariably lead to under-investment in the development of new varieties.

The conventional response to the problem of market failure has been to provide investment through public sector research—as evidenced by the establishment of land grant universities in the United States, public agricultural research institutions in Europe, and the large National Agricultural Research Systems (NARS) in several developing countries. The contribution of public research systems to the development of improved varieties has been spectacular. But financial support for public sector agricultural research has suffered a serious setback since the 1980s in both developed and developing countries. Alston, Pardey, and Smith (1998) report that in real terms between 1945 and the mid 1970s, in most developed countries, public expenditures on agricultural R&D grew more rapidly than in the rest of the post World War II period. Then in the mid 1970s, rates of growth in public R&D outlays slowed quite markedly and, in the 1980s, public R&D expenditures generally stagnated or declined. In the 1990s, however, public R&D expenditures recovered or began to increase again but at more modest rates of growth than in the 1960s or 1970s. This slow down in the growth of R&D agricultural spending has been a feature of developing countries as well. Maintaining previous levels of growth in public research expenditure may prove infeasible in both developed and developing countries. The fiscal constraints of the public sector, the emerging role of biotechnology in plant breeding (that calls for a magnitude of investment only very large players can afford), changing ideas about the applicability of IPRs to living materials and scientific advances that facilitate the enforcement of IPRs for seeds, have brought into sharp focus the question of IPRs for new plant varieties to provide incentives for private sector research.

If private investment in plant breeding has to be encouraged, then the

[1] The difficulties in segregating the benefits flowing from a new plant variety arise because productivity depends on other inputs as well (e.g., fertiliser, agronomic practices etc.) and it is difficult to separate out the contribution of a new variety to productivity

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problem of appropriability has to be addressed. This implies what some authors, such as Kloppenburg (1988), have called the 'commoditization' of seed. This thrust towards commoditization has probably been the most important factor in the emergence of the concept of IPRs over plant varieties. Successful commoditization requires that institutional barriers be placed on the self-reproducing characteristics of seeds and this is precisely what plant variety protection (PVP) legislations attempted to do. Scientific progress itself facilitated commoditization: for instance, the emergence of hybrids provided a technological solution to the problem of appropriability. The emergence of hybrids encouraged the participation of the private sector in plant breeding for some crops, such as maize in the US. PVP legislation can be seen as an attempt to address the problem of appropriability for self- and open-pollinated varieties. The operationalization of PVP was facilitated by the following developments:

1. The development of systematic botany, which permitted the unique description of varieties, based on morphological characteristics. This enabled a particular case of plant variety rights to be distinguished from any other case. Better breeding techniques made it possible to breed genetically uniform varieties. This facilitated the identifiability of individual varieties, which was a key element for the application of IPRs.
2. The increase in farm size and a decline in the number of farmers in developed countries, which drastically reduced the transaction costs of enforcing IPRs in relation to farmers.
3. The development of molecular techniques for identification of varieties and their parentage that facilitated the enforcement of IPRs in relation to imitators and competitors (Godden, 1998).

Since the 1960s, almost all developed countries have enacted PVP legislation and the International Convention for the Protection of New Varieties of Plants (UPOV) of 1961 attempted to harmonize the PVP legislation of member countries. There have been a few studies that have assessed the impact of PVP in the US and Latin American countries (Perrin, Kunnings, and Ihnen, 1983; Butler and Marion, 1985; Kalton, Richardson, and Frey, 1989; Babcock and Foster, 1991; Jaffe and Van Wijk, 1995; Butler, 1996; Frey, 1996; Alston and Venner, 1998). While PVP does appear to have facilitated private sector participation in the breeding of non-hybrid crops, the available empirical evidence suggests that the incentive effects of PVP may be fairly weak, as *farmers' and researchers' exemptions* appear to constrain the appropriation of returns. Thus, PVP has not brought the appropriability of returns from investment in self-pollinated crops anywhere near the levels reached with hybrid crops.

The quest for stronger protection has led to plant varieties being protected through patents in a number of countries. In the US, plant varieties became patentable as a result of a series of judicial decisions reinterpreting the existing patent laws *(Diamond* vs. *Chakrabarty* and *ExParte Hibberd* are two landmark cases) (Goss, 1996). Patents provide stronger protection because they are not subject to farmers' and researchers' exemptions. The scope of utility patents is wide because it allows a breeder to exclude others from *making*, *using*, or *selling* the seeds of the patented variety.

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Thus, PVP does not significantly improve the appropriability of returns from investment in self-pollinating varieties and patents are inherently more difficult to obtain because of the criteria of 'non-obviousness' and 'usefulness' that they involve. Besides, contractual arrangements can be difficult to monitor to detect infringements and costly to enforce. Under contractual arrangements, seed companies are restricted to contract remedies when a breach occurs and these remedies may cover only a fraction of the losses suffered by a vendor seed company due to infringement. The costs of IPR-related litigation to seed companies runs into millions of dollars each year. It is against this background that terminator technology can be seen as a technological solution to the problem of appropriability. In the context of changes in PVP laws that circumscribe the use of farm-saved seed and the contractual arrangements, which have come into vogue for transgenic varieties, the terminator technology represents only a better technique of enforcement of IPRs, *rather than a change of principle governing what is legitimately appropriable*. The technology has emerged because the existing institutional mechanisms for enforcement are inadequate, expensive to use, and imperfect. It promises to drastically reduce the transaction costs for enforcement of IPRs *vis-à-vis* farmers. It is a technological response to an institutional problem.

4. A model of appropriability for plant varieties

The appropriability of returns from research investment can be calculated by adapting the framework developed by Scherer (1986) for the economic analysis of the allocation of R&D resources under rivalry. Farmers need only buy new seed after five to seven years when farm-saved seed starts losing its vigour (giving lower yields) or suffering from 'genetic drift'.

Table 1. *A model of appropriability for plant varieties*

Variables and their description	
V	Potential quasi-rents (total revenues less costs) attainable from the sale of a new variety. It is initially assumed that costs and prices are constant and hence V does not depend upon the number of firms.
TL	Innovator's new variety introduction date.
TF	Imitator's product innovation date.
ρ	Discount rate.
γ	Penetration co-efficient: γ is a co-efficient that indicates the proportion of unexploited market potential captured each year. The value of γ depends upon the yield or agronomic superiority of the variety, marketing efforts, etc. The innovator moves toward realization of full market potential at the rate of 100γ per cent per year following introduction.
S_F	Imitators' target market share. It is assumed that this depends on the share of imitators in related markets and other strengths.
μ	Rate at which the imitator moves toward his market share. It is assumed that the imitator moves toward full realization of his share at the rate of 100μ per cent per year following imitation.
α	Percentage of farmers who buy replacement seed in the current year having bought fresh seeds the previous year.

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Table 1. *Continued*

Scenario	*Expression for innovator's discounted quasi-rents in the presence of imitation*
Equation 1: Full replacement of seed by farmers each year	$V_L = \int_{TL}^{\infty}(l - e^{-\gamma(t-TL)})Ve^{-\rho t}\,dt - \int_{TF}^{\infty}(S_F - S_F e^{-\mu(t-TF)})Ve^{-\rho t}\,dt$ $= Ve^{\rho TL}\left(\frac{1}{\rho} - \frac{1}{\gamma+\rho}\right) - S_F Ve^{-\rho TF}\left(\frac{1}{\rho} - \frac{1}{\gamma+\rho}\right)$ (1)
Equation 2: No replacement by farmers after adoption of variety	$V_L = \int_{TL}^{\infty}(e^{-\gamma(t-TL)} - e^{-\gamma(t-TL+1)})Ve^{-\rho t}\,dt - \int_{TF}^{\infty}S_F(e^{-\gamma(t-TL)} - e^{-\gamma(t-TL+1)})Ve^{-\rho t}\,dt$ $= \frac{Ve^{-\rho TL}}{\gamma+\rho}(l - e^{-\gamma}) - \frac{VS_F}{\gamma+\rho}(e^{-\gamma(TF-TL)-\rho TF})(l - e^{-\gamma})$ (2)
Equation 3: Seed replacement by a proportion of farmers each year	$V_L = \int_{TL}^{\infty}\left[(1 - e^{-\gamma(t-TL+1)}) - (1 - e^{-\gamma(t-TL)})\right]Ve^{-\rho t}\,dt + \int_{TL}^{\infty}(1 - e^{-\gamma(t-TL)})\alpha Ve^{-\rho t}\,dt - \int_{TF}^{\infty}S_F\left[(1 - e^{-\gamma(t-TL+1)}) - (1 - e^{-\gamma(t-TL)}) + \alpha(1 - e^{-\gamma(t-TL)})\right]Ve^{-\rho t}\,dt$ $= \frac{V}{\gamma+\rho}(e^{-\rho TL} - e^{-\gamma-\rho TL}) + \alpha Ve^{-\rho TL}\left(\frac{1}{\rho} - \frac{1}{\gamma+\rho}\right) - VS_F e^{-\rho TL}\left[\frac{(1-\alpha)e^{-\gamma(TF-TL)}}{\gamma+\rho} - \frac{e^{-\gamma(TF-TL+1)}}{\gamma+\rho} + \frac{\alpha}{\rho}\right]$ (3)
Equation 4: Replacement of seed every 5 years	$V_L = V\frac{1}{\gamma+\rho}\left[e^{-\rho TL} - e^{-\gamma-\rho TL}\right] + V\frac{1}{\gamma+\rho}\left[e^{-\rho(TL+5)} - e^{-\gamma-\rho(TL+5)}\right] - \frac{VS_F e^{-\rho TL}}{\gamma+\rho}\left[e^{-\gamma(TF-TL)} - e^{-\gamma(TF-TL+1)}\right] - \frac{VS_F e^{-\rho(TL+5)}}{\gamma+\rho}\left[1 - e^{-\gamma}\right]$ (4)

Four different assumptions about farmer seed replacement behaviour are considered: 100 per cent replacement of seed every year, no replacement, replacement by 20 per cent adopting farmers each year and replacement by all farmers every five years. Table 1 describes the variables used in the model and the expressions derived for the discounted value of the

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Table 2. *Summary of innovator's discounted quasi-rents for different scenarios*

	No imitation		*With imitation*	
Full replacement by farmers	396	(100%)	240	(60%)
No replacement by farmers	39	(9%)	33	(8%)
Replacement by 20% farmers	118	(30%)	75	(19%)
Replacement every five years by farmers	58	(15%)	41	(10%)

innovator's stream of quasi-rents for different patterns of seed replacement behaviour by farmers.

In this adaptation of Scherer's model, it is assumed that the new variety opens up a new market. After the introduction of a new variety, the innovator will not realize the whole of the annual potential quasi-rent immediately because it takes time for a variety to diffuse to farmers and acquire its full potential market share. Given the researchers' exemption, imitators can introduce rival varieties with a time lag. But imitator's varieties will also acquire their potential market share only over a period of time. Table 2 illustrates the impact of farmer seed replacement behaviour on the innovator's discounted stream of quasi-rents using the following values of the parameters:

$TL = 4$ (It takes four years to develop a new variety from the start of the breeding programme)
$TF = 2$ (Imitators develop a rival variety two years after the introduction of the new variety)
$\gamma = 0.4$ (40% of the unexploited market potential is captured each year)
$\alpha = 0.2$ (Farmers replace seed every five years)

Under these assumed values, the maximum discounted value of the innovator's quasi-rent is 396 (the units are arbitrary) when there is no imitation. Relative to this annual potential quasi-rent of 100 per cent, the value of 240 when there is imitation, with a time lag, means that the quasi-rent is only 60 per cent of the maximum. But, with no replacement by farmers, the discounted value in a situation with imitation falls drastically to 33 (just over 8 per cent of the maximum achievable), while other replacement patterns generate intermediate values. If the discounted value with full replacement is taken to be the appropriation of returns from hybrids, then it is clear that under reasonable assumptions, self-pollinated varieties yield less than 30 per cent of the return from hybrids (assuming that development costs are similar).

5. The effect of appropriability on private R&D investment

The important question is whether this dramatic difference in appropriation of returns from a new variety when farmers replace seed every year gets reflected in the resources allocated to research. The evidence from the US suggests that there is in fact a strong link between appropriability and private plant breeding efforts. The US data, reported in table 3, show that the investment in hybrid maize is over eight times the figure for self-pollinated wheat (Fuglie *et al*., 1996). Since the value of the corn crop is about three times the value of wheat output, this means that R&D per unit of value is about 2.5

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Table 3. *Sales, private plant breeding and trends in seed prices and yields, US (1975–1992)*

Crop	*Seed sales*	*Private plant breeding*	*Seed cost*	*Share of seed purchased*	*Growth in seed price*	*Annual growth in crop yields*
	Million 1989 dollars		*Dollars/acre*		*Percent*	
Corn	1031	112.9	21.09	95	4.75	1.33
Wheat	256	13.5	8.92	40	.97	1.13

Source: Fuglie *et al*. (1996).

times higher for hybrid corn. The share of purchased seed for corn is 95 per cent while for wheat it is only 40 per cent (again, about 2.5 times higher) and the growth in yields is also significantly higher for the hybrid crop.

In an earlier study, Thirtle (1985) estimated the contribution of biological inputs to the growth in farmers' yields in the US after accounting for changes in fertiliser, labour, machinery, and land use and allowing for substitution among inputs. Biological technical change increased corn yields by 1.7 per cent per year, wheat yields by 1.5 per cent, soybean yields by 1.1 per cent, and cotton yields by 0.5 per cent. Thus, the hybrid crop had more rapid technical progress, probably as a result of the higher R&D intensity. Also, the contribution of biological inputs to yield gain appears to increase with the appropriability of returns. Fuglie *et al*. (1996) estimate that for crops grown with hybrid seed, seed companies appeared to capture 35–48 per cent of the value of improved seed with the remainder going to farmers. For non-hybrid crops (wheat, soybeans, and cotton) seed companies obtained even lower shares of yield gains, from 12 to 24 per cent. Figure 1 shows the share of genetic yield growth for these crops

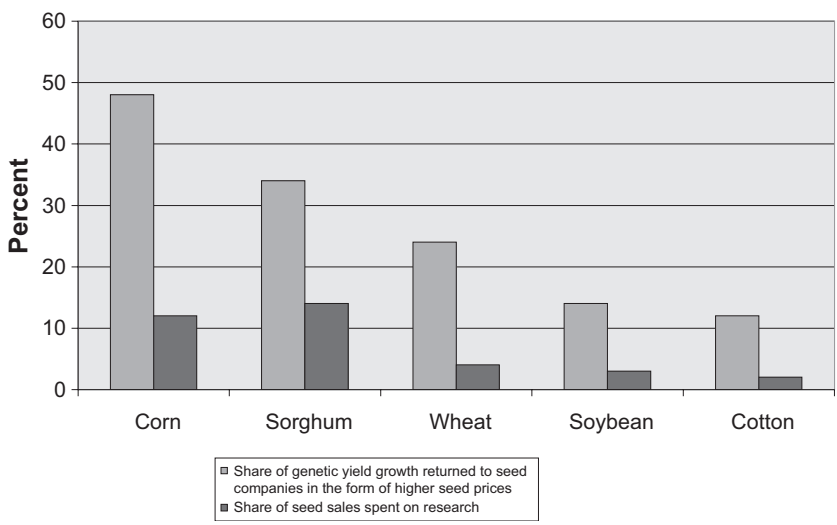


Figure 1. *Appropriability and private investment in plant breeding*
Source: Fuglie *et al*. (1996).

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captured by seed companies in the form of higher seed prices and the share kept by farmers, on the assumption that half the growth in farmer yields can be attributed to genetic improvements and the other half to other factors. The crucial point is that for the hybrid seed crops, seed companies invested over 10 per cent of seed sales in research. For the non-hybrid seed crops, only 4–5 per cent of seed sales were reinvested in research (again, 2–2.5 times higher). Fuglie *et al*. (1996, p. 41) conclude, 'The inability to capture a larger share of the gains form breeding non-hybrid crops served as a disincentive for seed companies to invest more in research.'

If terminator technology were to be applied to self-pollinated crops, appropriability of returns would increase dramatically and the level of research expenditures could potentially go up to the level of hybrid crops, which could be an increase of two to three times the current level. The resultant increase in the rate of yield gain and the cumulative impact on production could be very substantial.

The model and the evidence in this section suggest that terminator technology can dramatically improve the appropriability of returns from innovations in plant varieties. The remainder of this section empirically tests the relationship between appropriability and the level of private research investment in agriculture, using a model adapted from Alfranca and Huffman (1999). The econometric relationship they suggest is:

$$\begin{aligned}\mathrm{Ln}(PRAGRD)_{it} = CONSTANT_i + b_1\mathrm{Ln}(CEREAL)_{it} + b_2\mathrm{Ln}(PRRDSTK)_{it-1} \\ + b_3\mathrm{Ln}(PUBRDSTK)_{it-1} + b_4\mathrm{Ln}(PRSPILL)_{it-1} + b_5 INTERACTION1 \\ + b_6 INTERACTION2 + e_{it} \qquad (5)\end{aligned}$$

The variables are defined and their sources noted in table 4 and the *i* subscript indexes countries and *t* indexes time periods. The countries included were Belgium, Canada, Finland, France, Germany, Ireland, the Netherlands, Norway, Spain, and Sweden. The selection of countries was mainly dictated by the availability of data and the necessity of choosing countries that have had a fairly well-established IPR regime for a reasonable length of time. The time period used in the regressions was 1989–1997, except for Belgium where it was 1990–1997.

In this model, it is postulated that the level of research investment in agriculture in a country is a function of the size of the market for inputs, the stocks of private and public agricultural research and development and the strength of the intellectual property rights regime. A larger market size (proxied by the volume of cereal production) is expected to provide more opportunities for profitable private research and is expected to positively influence the level of private investment. A larger stock of private R&D could be expected to increase private investment because pre-existing research capability in the private sector is a prerequisite for private investment and a larger stock of private R&D may mean that market opportunities can be exploited better. However, a larger stock of private R&D could exert a negative influence on private investment if the potential for innovation is getting exhausted. This could arise, for example, in a situation where it is becoming increasingly difficult to achieve yield increases through new varieties. Public R&D stock will affect private R&D

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Table 4. *Appropriability and the level of private R&D investment: variables*

Variable	*Description*	*Source*
Dependent variable: $PRAGRD_{it}$	Private investment in agricultural R&D	OECD *Basic Science and Technology Statistics*; R&D performed by business enterprise in the sector 'Agriculture, Forestry and Fisheries'
$CEREAL_{it}$	Volume of cereal production (proxy for market size for agricultural inputs like seeds)	FAOSTAT
$PRRDSTK_{i,t-1}$	Lagged value of stock of private R&D	OECD *Basic Science and Technology Statistics*; annual R&D flows converted to stocks using PIM (12.5% depreciation); constant 1990 US$ converted to PPPs using OECD's PPP conversion tables
$PUBRDSTK_{i,t-1}$	Lagged value of the stock of public R&D	OECD *Basic Science and Technology Statistics*; Government outlays for R&D in the 'Agriculture, Forestry and Fisheries' sector; deflated to constant prices using OECD's GDP deflator and then converted to PPPs using OECD's PPP conversion tables.
$PATENT_{it}$	Strength of IPRs	Index prepared by Ginarte and Park (1997)
$PRSPILL_{i,t-1}$	Lagged value of stock of private R&D in all the other countries.	Sum of the R&D stock of other countries in PPPs.
$INTERACTION1_{i,t-1}$	Lagged value of Ln(*PRRDSTK*)* Ln(*PUBRDSTK*)	
$INTERACTION2_{i,t-1}$	Lagged value of Ln(*PRRDSTK*)* *PATENT*	

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positively if public and private R&D are complements. This could be true in the classic scenario where the public sector focuses on basic research and creates new applied research opportunities for the private sector. However, if public and private research focus on the same area of research and compete with each other, the public R&D could crowd out private R&D. This could very well be the case when both the public and private sector compete in developing commercial cultivars of agricultural crops.

The spill-in of private R&D from other countries can be a positive externality that promotes domestic private research. But, in the context of plant varieties, the effect is not very certain. If varieties developed abroad by private research spill in directly into the domestic market then domestic private investment could be discouraged. The coefficient of the interaction term between public and private research investment (*INTERACTION*1) will depend on the nature of the relationship between public and private research—if public and private research are complements then the co-efficient can be expected to be positive. If public investment tends to crowd out private investment then the co-efficient can be expected to be negative. The interaction between the private R&D stock and the strength of the IPR regime (*INTERACTION*2) can be expected to have a positive effect on private investment. This is because for a given level of IPR enforcement, the returns appropriated by the private sector will be greater, the larger the private R&D stock. A strong IPR regime will have a greater effect on private investment if a country has a large private research base to start with.

The equation was estimated for an unbalanced panel and the fixed effects specification was chosen in preference to random effects, based on the Hausman test statistic. The results, reported in table 5 show that the model explains over 90 per cent of the variance in private R&D. All the co-efficients are significantly different from zero at the 5 per cent level of significance, except for that on Ln*CEREAL*.[2] Both public and private R&D stocks have negative effects on the level of private R&D and so do

Table 5. *Appropriability and the level of private R&D investment: results*

Dependent variable: LnPRAGRD		*Adjusted* R^2 *= 0.916*		
Variable	*Coefficient*	*Error*	*t-statistic*	*P-value*
Ln*CEREAL*	−0.137	0.521	−0.262	[.794]
Ln*PRRDSTK*(−1)	−8.660	3.098	−2.795	[.007]
Ln*PUBRDSTK*(−1)	−5.175	2.573	−2.012	[.049]
Ln*PRSPILL*	−3.174	1.064	−2.983	[.004]
*INTERACTION*1(−1)	1.017	0.482	2.108	[.039]
*INTERACTION*2(−1)	0.568	0.270	2.100	[.039]

Hausman test of H_0: random effects vs. fixed effects: CHISQ(6) = 16.955, p-value = [0.0095]

[2] Ln*CEREAL* is probably not significant because it only represents the volume of production and does not fully capture the size of the input market in different countries. Countries with a larger volume of cereal production also appear to have a lower seed replacement rate.

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Table 6. *Elasticities of pivate R&D with respect to the explanatory variables*

Elasticity of dependent variable with respect to:	
Privat Private R&D stock	−2.2
Public R&D stock	−0.95
Spillovers of private R&D	−3.174

spillovers of R&D from other countries. However, the interaction between public and private R&D appears to have a positive impact on private investment (in addition to the crowding out effect of public R&D referred to above). One explanation for this could be that there is a component of public sector activity (e.g. germplasm improvement and diversification) that substantially increases the potential for private sector investment (in the 'applied' development of new varieties), and a large private R&D base is necessary to fully exploit the opportunities created by public sector research. Lastly, the key result is the positive impact on private R&D of the interaction of patents and the private R&D stock, which supports the contention that is often made, that IPRs will have positive effects on private investment only if there is a pre-existing research capability.

The elasticities of the dependent variable with respect to the key explanatory variables are reported in table 6. These take account of the direct effects and the interaction terms and are calculated at the variable means. The elasticity with respect to private R&D stocks is strongly negative. This suggests that with a given stock of knowledge and previous discoveries, the potential for profitable innovation through private research declines rapidly as private investment proceeds. The negative effect is mitigated to an extent by the positive interaction between private and public R&D. The elasticity of private agricultural research investment with respect to public R&D stock is negative but much less strong. This suggests a crowding out effect and may be true for that component of public R&D, which directly competes with the private sector, such as the development of commercial varieties. Spill-ins appear to reduce the potential for domestic private R&D, so foreign R&D appears to be a substitute for domestic R&D.

Thus, it appears that terminator technologies, which are akin to stronger enforcement of IPRs, can promote private investment, but their impact depends on the pre-existing level of research capability (private R&D stocks). Innovation potential diminishes rapidly with the build up of private R&D stocks. The shifting of the 'innovation frontier' requires the positive effect produced by the interaction between public and private R&D. The original terminator patent which was granted jointly to USDA and Delta and Pineland Company, and which opened up a whole new area for innovation (seeds that could have traits switched on or off), would be a good example of this. Countries that consider the adoption of terminator technologies in the quest for higher levels of private investment would do well to look at the existing levels of research capability in the private sector. They would also need to support the kind of interaction between the public and the private research that creates further opportunities for private sector research.

https://doi.org/10.1017/S1355770X0300010X Published online by Cambridge University Press

6. Assessing the potential benefits and costs to developing countries

The previous section provides clear evidence that increases in appropriability lead to greater private R&D investment and faster growth in yields. A further potential gain is that terminator technology may reduce the duration of protection. Under PVP this currently ranges from 18 to 25 years, which is longer than the duration for patents. With improved appropriability, it may be possible to reduce the period of protection to say ten years. This would reduce the 'deadweight' loss associated with IPRs and enable faster diffusion of varieties.

A further gain is that in combination with certain types of contractual arrangements discussed above, terminator technology could facilitate perfect price discrimination by seed companies. Each farmer would pay a price for seed that would be related to the benefits derived from its use. Perfect price discrimination would allow a seed company to cream off the entire consumer surplus. But, it is also a well-known result in economic theory that under perfect price discrimination the monopolist produces the competitive level of output and the allocation of resources is efficient. Thus, price discrimination could result in an expansion of output, relative to the current situation of imperfect competition.

The trend towards monopoly may in any case limit the choices open to farmers. Theoretically, it can be argued that farmers will buy terminator seeds only if they provide higher returns even after taking into account the higher costs of seeds and other inputs that they would be compelled to buy. This assumes that farmers would have a choice and that seed markets would at least be 'constestable' if not competitive. However, the seed industry has seen consolidation through take-overs and mergers at a frightening pace. In the first wave of acquisitions and mergers in the 1960s and 1970s, many large chemical, oil, and food corporations acquired many medium- and small-sized seed companies. Another round of mergers in the 1980s saw many of these food, oil, and chemical companies sell their interest in the seed business to agricultural chemical firms. The 1990s have seen the take-over of many small biotechnology firms by the large seed firms and mega-mergers involving the seed giants (Butler, 1996). In developed countries, the new life science companies that combine crop biotechnology with agro-chemical and seed production dominate the seed industry. The six big multinationals[3] have a very large market share for seeds of certain crops. For instance, Monsanto could have controlled 85 per cent of the cotton seed market in the US if its merger with Delta and Pine had come through. If these companies all introduce terminator technology, there is a real danger that farmers may not be able to have a choice. They may not be able to choose improved agronomic characteristics without also choosing terminator technology. Local adaptation of varieties and community-based seed supply systems would cease to exist, with adverse consequences for biodiversity on farmers' fields.

The maintenance of some kind of competitive pressure, so necessary for

[3] The global seed industry continues to see a spate of mergers and acquisitions. At the time of writing the big six multinational were—Aventis, Dow, Dupont, Monsanto, Novartis (Syngenta), and Astra-Zeneca.

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innovation, would depend on the 'freedom to operate' that other players (such as public research systems, universities, and competing companies) have. 'Freedom to operate' will depend greatly on how IPRs are applied to biotechnological processes. Terminator technology by itself confers no agronomic benefits. To be commercially successful it must be bundled with other useful agronomic traits and these traits must not be available otherwise. Increasingly, these useful agronomic traits will be ones that are engineered through biotechnology with the associated processes being patented. It is only then that companies will be able to retain exclusive use of the desirable agronomic traits. The development of new varieties in the future may require access to a number of biotechnological processes, all patented by different companies. Unless an efficient system is developed for licensing the component biotechnological processes, there could be gridlock in the development of new varieties. The scope of protection accorded to biotechnological processes needs to be carefully modulated if such a gridlock is to be avoided. There are indications that many International Agricultural Research Centres (IARCs) are finding that they cannot work on biotechnology-based varietal improvement without licenses for component processes from seed companies (Cohen *et al*., 1998). The ability of universities and public sector institutions to license processes often depends on their having a portfolio of patents for cross licensing. Without the ability to cross license, their 'freedom to operate' would be severely restricted. The important issue is whether the public sector and other players will be able to provide improved varieties without terminator genes and offer a measure of competition.

In acceding to the TRIPs Agreement,[4] all developing countries have committed themselves to provide some form of 'effective' IPRs for plant varieties. Several developing countries are in the process of drafting their legislation. Some are attempting to formulate a *sui-generis* system that balances breeders' rights with farmers' rights and recognition of their contribution to the maintenance and enhancement of biodiversity. The debate about the terminator, therefore, is not about the fundamental desirability of IPRs for plant varieties but about a particular technique of enforcement. The fact that terminator technology has emerged in response to inadequate IPR institutions must make developing countries ponder about the kind of IPRs they need to put in place, if they really intend to encourage private investment. Stronger IPR systems may even obviate the need for development of such technologies.

An important factor, which will determine the response of developing countries to the new technology, will be the approach followed by the Consultative Group on International Agricultural Research (CGIAR) institutions. This will be especially true of those countries that rely on the International Agricultural Research Centres for new varieties. The CGIAR system has apparently made a decision that none of its institutions would use the terminator technology for the development of new varieties for developing countries in view of the potential deleterious effects of the

[4] Agreement on Trade-related Aspects of Intellectual Property Rights, which is part of the agreement establishing the WTO.

https://doi.org/10.1017/S1355770X0300010X Published online by Cambridge University Press

technology. This could have important implications for the commercialization of the new technology in developing countries.

Quite independently of the CGIAR system, developing countries will have to decide on their response to the emerging technology. Very little is known about the ecological impacts of terminator varieties. The nature of interaction of terminator varieties with other crops and species is not known. It remains to be assessed whether terminator varieties are, accidentally or otherwise, capable of rendering the seeds of (adjacent) non-terminator varieties also sterile. This is a critical issue for developing countries where millions of subsistence or resource-poor farmers depend on farm-saved seed. If terminator varieties can render the farm-saved seed of non-terminator varieties sterile, even in limited number of situations, there will a potential for a great deal of social unrest. Similarly, if terminator varieties have artificially lowered resistance to certain diseases or infestations, then the unintended build up of pathogens in the fields of both users and non-users would be a crucial issue. The large-scale use of antibiotics that currently appears to be a feature of the technology is also an important matter of concern. What developing countries require at this stage is capacity building for making detailed ecological and economic impact assessments. If improved varieties of the private sector in developed countries are going to be invariably bundled with the terminator in the future, then developing countries will have to assess the trade-off between increased productivity through the use of these varieties and the retention of farmers' privileges. The existence and severity of such a trade-off will depend on the sustained capability of NARS and IARCs to produce improved varieties without the terminator technology. Their 'freedom to operate' in the brave new world of IPRs will be a critical issue. There may be a case for selective adoption of the new technology for certain crop species. If the capacity for ecological and economic impact assessment is not built up, then policy will inevitably be determined by emotive, populist rhetoric.

The introduction of terminator technology in developing countries would involve interface with several elements of the regulatory framework:

1. Quality control legislation.
2. Varietal release and notification procedures.
3. Intellectual property rights legislation.
4. Policies on export and import of seed.
5. Quarantine regulations.
6. Approval procedures and marketing regulations for agro-chemicals.
7. Policy governing foreign direct investment in the seed industry.

The existing regulatory framework in developing countries may be not adequate to deal with terminator technology. Several elements of the regulatory framework may have to be modified substantially in a co-ordinated and coherent fashion to respond to the challenges posed by terminator technology. Wherever the regulatory framework is weak, developing countries will have to contend with the possibility of surreptitious introduction (or introduction through informal channels) of terminator

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varieties. This would be particularly important in countries where varietal registration is not mandatory for marketing of seeds and would be more difficult to handle than introduction through the organized sector.

The policy in most developing countries has been to push for increasing the seed replacement rate (SRR) and quicker adoption of new varieties. However, even in many Green Revolution areas like the Indian Punjab, SRRs have been very slow to increase. This happens either because farmers cannot afford to replace seed every year, or because farmers do not perceive the advantages of replacing seed or because farm-saved seed is almost equal in quality to bought-in seed. Terminator technology by its very nature can swiftly push up SRRs and also increase varietal turnover, as farmers will be more likely to change to new varieties if they replace seed every year. Developing countries have a very difficult decision to make in deciding whether terminator technology should be used as an instrument to improve SRRs and encourage varietal replacement.

Developing countries will also have to consider the impact of terminator technologies on foreign direct investment in the seed industry. There may be a tendency for the investment to flow to those countries that accept the use of this technology. Even if better appropriability generates more research investment, the location of that investment would still be an important issue for developing countries. Approval of terminator technology can greatly increase volumes for the domestic seed industry provided it has access to the technology. The important question will be whether the domestic industry will be able to compete with terminator varieties introduced from outside. The competitive position of the domestic seed industry may depend on whether and on what terms the technology is made available to them.

The public sector in developing countries could see a major revival of its role in developing countries as the developer and producer of non-terminator varieties that may be very important for resource-poor farmers. The important question for the public sector will be whether lack of access to private sector material owing to IPRs will hamper it. Or will access to germplasm in international collections such as those of the CGIAR system be adequate for the development of competing varieties?

In assessing terminator technology, developing countries will have to address the Green Revolution questions as well. Which farmers and which regions will be the early adopters of the new technology in developing countries? Will the adoption of the new technology be different between rich and poor farmers? Will the adoption of terminator technology follow the green revolution pattern of adoption of high-yielding varieties? What will be the implications for credit requirements? Is the technology a coercive one in the sense of compelling unwilling farmers to adopt it?

7. Concluding observations

Terminator technology has emerged as a response to the inadequacies and imperfections of existing IPR institutions. By providing a technological response to the problem of inadequate appropriability, it can be a corrective to market failure. At a time when public research systems everywhere are faced with declining budgets and yield gains are becoming

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increasingly dependent on the application of expensive biotechnology, it has the potential to increase private research spending on self-pollinated crops to the level of hybrids. The resultant productivity gains may well be substantial. While better appropriability can provide additional resources for investment, there are legitimate concerns about the use of the technology. The environmental consequences of the technology can be far-reaching and complex and need to be carefully assessed. The use of the technology in an industry that is oligopolistic and highly concentrated may imply that farmers lose their right to choose, and competitive pressures that are so necessary for innovation may cease. Besides, the gridlock creating potential of IPRs can stifle, rather than promote, the development of new varieties. The scope of protection for biotechnological processes in the IPR system needs to be carefully modulated if such adverse impacts are to be avoided. But the most important lesson to be drawn from the emergence of this technology is this: In a process of market-led development, technological change will respond not only to relative factor scarcities but also to institutional bottlenecks. The development of a technology with no agronomic benefit to farmers may appear to be a huge waste of resources, but the market *will* devote resources to the reduction of transaction/appropriation costs.

Developing countries face many difficult choices in responding to this technology. If a large part of varietal improvement in the future is going to be bundled together with terminator technology, then it may not be possible for them to ignore the technology altogether. Productivity is of even greater concern to them than it is to developed countries. Potential productivity gains will have to be weighed against the social costs arising from the coercive element of the technology. What they need at this stage is the capacity to evaluate its ecological, economic, and social impacts, selectively apply it where appropriate and upgrade their regulatory system to deal with the technology. They will need to seriously think about appropriability and intellectual property rights.

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