Crop Research Incentives in a Privatized Industry:

A Stochastic Approach

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Abstract

We model today's privatized crop research industry as a small number of firms, developing and selling differentiated products to heterogeneous producers. Crop variety research is modeled as a search process, which allows us to differentiate between applied and basic research and recognize research as a stochastic process. We use the framework to develop a number of propositions regarding private research incentives, the spillovers of knowledge, and the impact of public policy. The results suggest an underinvestment in research even when property rights have been established.

Key words: search process, stochastic process, biotechnology, IPRs, applied R&D, basic R&D, imperfect competition, differentiated products, heterogeneous producers.

1. Introduction

Crop improvement research has recently changed a great deal for many crops. During the 20th century, public sector was undertaken most of the research investment and the products of research were held in the public domain (Huffman and Evenson 1993). Recently, the private sector has played a dominant role in R&D activities and for many crops most of the research outcomes are privately owned. The establishment of improved IPRs and the introduction of modern biotechnology are the main drivers of these changes. IPRs and biotechnology have changed the nature of agricultural products from non-rival and non-excludable to excludable goods, which in turn, allows private firms retain most of the economic rent of their investments (e.g., Fulton 1997, Moschini and Lapan 1997). The inherent non-rival nature of research products creates increasing returns to scales and scope (Romer 1990). These economies, along with freedom to operate concerns, tend to create a concentrated agricultural research industry (e.g., Fulton and Giannakas 2000, Lesser 1998, Lindner 1999), which is consistent with the observed consolidation of the industry. The economic implications of these recent changes are not fully understood.

Most of the economic literature on the returns of agricultural research examines the economic implications of public R&D in the absence of IPRs and under a perfectly competitive structure (for review and summary of this literature see Alston, Marra, Pardey and Wyatt 2000). A number of more recent studies show that while IPRs create incentives to invest they also create market power and efficiency losses (e.g., Moschini and Lapan 1997, Alston, and Venner 2000). Several studies have examined the effect of public research investment on private investment analytically (e.g., Warr 1982, Roberts 1984, Bergstrom et al., 1986) and empirically (for review and summary of this literature see Steinberg 1993, and David, Hall and Toole 1999), and have produced inconclusive results regarding the direction and the magnitude of the effect. Furthermore, most economic studies either do not distinguish between basic and applied research, or assume a linear pipeline relationship (e.g., Grilliches 1986, Adams 1990, Huffman and Evenson 1993, Thirtle et. al 1998). Recently, a few studies modeled the link between basic and applied research with more complexity and in some cases in a nonlinear manner (e.g., Rosenberg 1990 and 1991, Pavitt 1991, Brooks 1994, Dasgupta and David 1994, Pannell 1999, Rausser 1999). Finally, few research contributions model agricultural research as a stochastic process in a very basic framework (e.g., Evenson and Kislev 1976).

The objective of this study is to examine the today's privatized research industry characterized by a small number of research firms with market power, developing and selling differentiated products to heterogeneous producers. Specifically, we examine the private incentives for R&D, the research spillovers between public and private research and between basic and applied research, and whether the private investment is socially optimal. Rather than a standard production process we use a search process to generate research outcomes. Search process is more realistic way to model research given that research is a stochastic process with sporadic outcomes. Moreover, the manner in which basic research affects applied agricultural research is embodied in the search model.

The remainder of the paper is organized into three sections. Section 2 develops the analytical framework for this analysis. Section 3 presents the results of the model in the form of propositions and discusses the policy implications. This section concludes with an examination of whether the total amount of private research is socially optimal. Finally section 4 contains a summary and the concluding comments of the paper.

2. Analytical (Theoretical) Development of the R&D Model

The behavior of the imperfectly competitive research firms is modeled in three stages. In the first stage, each firm (private and/or public) decides on the optimal number of research trials, which creates a specific expected yield for their differentiated variety. In the second stage, given this yield, each research firm chooses the price they will charge for their variety. In the third stage, farmers look at the prices and yields of the varieties and choose which variety to purchase on the basis of net returns. The equilibrium outcomes for model are solved using backward induction.

Third Stage: Farmers' Demand for the Variety

There are N farmers. All farms are the same size, k acres, and each farmer (i) has homogeneous land with a unique characteristic ψ_i (e.g., soil quality, weed infestation, management skills) that varies across farms. To simplify the analysis, the characteristic ψ_i is uniformly distributed between 0 and 1. Farmers choose to purchase either variety A or variety B from firm A or B respectively. Variety A is best suited to farmers for land characteristic $\psi_i=0$ while variety B is best suited for $\psi_i=1$.

The objective of each farmer i is to maximize profit by selecting the proportion of area grown with variety A, ϕ_i, or variety B, $1-\phi_i$ subject to the inequality constraint $0 \le \phi_i \le 1$. It can be written as:

$$\max_{\phi_i} \Pi_i = sp[\Delta y^A+\tau(1-\psi_i)]k\phi_i - k\phi_i w^A + sp[\Delta y^B+\tau\psi_i]k(1-\phi_i) - kw^B(1-\phi_i) \qquad s.t. \quad 0 \le \phi_i \le 1 \tag{1}$$

where:

k = the area seeded by each farmer

ϕ_i = the proportion of area seeded to variety A

w^A = the price of seed of variety A

w^B = the price of seed of variety B

p = the price of output

ψ_i = the land characteristic of farmer i

τ = the change in yield associated with a unit change in the differential attribute

$\Delta y^A+\tau(1-\psi_i)$ = the yield of variety A for producer of characteristic ψ_i

$\Delta y^B + \tau\psi_i$ = the yield of variety *B* for producer of characteristic ψ_i
s = the proportion of the value generated from the variety that a farmer is willing to pay in the market place to purchase the variety directly from the breeding firm

The value of $\hat{\psi}_i$ --which is the land quality of the farmer who is indifferent between variety *A* or *B* is equal to:

$$\frac{[\Delta y^A - \Delta y^B + \tau] - w^A + w^B}{2\tau} = \hat{\psi}_i \quad (2)$$

All farmers with land quality less than $\hat{\psi}_i$ purchase variety *A*, while all farmers with land quality greater than $\hat{\psi}_i$ purchase variety *B*. Given that $\hat{\psi}_i$ is uniformly distributed between 0 and 1, then the market share of variety *A* is defined by $\hat{\psi}_i$.

The demand for variety *A* is equal to the product of the number of farmers, the amount of acreage each farmer has, and the market share for variety *A* ($Q^A = Nk\hat{\psi}_i$). Given that we choose units of quantity such that *Nk* is equal to 1, then the demand for variety *A* is equal to the market share for variety *A* ($Q^A = \hat{\psi}_i$).

Second Stage: Pricing of the Varieties

Having estimated farmers' demand for varieties *A* and *B*, the optimal pricing by firms *A* and *B* can be derived. The research firms *A* and *B* sell differentiated varieties to a group of heterogeneous farmers. A Bertand assumption is made to model competitive behavior. Each firm sets the price of its variety assuming the other firms price remains fixed. At the Nash equilibrium, neither firm can achieve a higher profit by changing the price charged for its product. The firms operate in a single period and pick a price level, where marginal revenue of the residual demand facing each firm from the sale of their variety is equal to the marginal cost of marketing and reproducing the seed. The objective of firm *A* is to maximize its profits, which is:

$$Max\ \Pi^A = w^A \hat{\psi}_i - L\hat{\psi}_i \quad (3)$$

where *L*= marginal cost of marketing and reproducing of the seed

Taking the first-order condition (F.O.C) and solving for seed price w^A and w^B, the best-response function of firm *A* and *B* can be computed. Substituting firm *B's* best-response function into firm *A's* best-response function, the Nash equilibrium can be determined where the price charged by firm *A* is equal to w^{A*}, while for firm *B* it is equal to w^{B*}:

$$w^{A*} = \frac{sp[\Delta y^A - \Delta y^B]}{3} + sp\tau + L \quad (4)$$

$$w^{B*} = \frac{sp[\Delta y^B - \Delta y^A]}{3} + sp\tau + L \quad (5)$$

The reduced form for the optimal market share for variety *A* is gives by:

$$\psi_i^* = \frac{[\Delta y^A - \Delta y^B]}{6\tau} + \frac{1}{2} \quad (6)$$

First Stage: Optimal Investment

The optimal research investment for firm *A* and firm *B* is derived given farmers' demand for the varieties and the optimal pricing of the varieties by the firms. Higher yielding varieties are discovered through a search process. The expected success of the breeding program will be dependent on the genetics of parent varieties, and the number of research trials. As described by the theory of extreme values the expected yield of the highest yielding offspring found will be an increasing and concave function of the number of research trails. In this normative approach, the optimal search behavior is estimated as the difference between the expected gain from the search and the cost of the search (e.g., Stigler 1961; Nelson 1970)[1].

The search process is a sequence of independent experiments composed of n_t trials. In a breeding program the crop breeders will typically cross two parent varieties and will use research trials to search among the offspring for the highest yielding genotype with desirable agronomic and quality characteristics. For simplicity, it is assumed that each trial is a random draw from a population that results in a single observation or outcome (specific yield level). Hence, the control variable is the number of trials (the extent of experimentation) and the state variable is the current yield level. The outcome of the experiment is the observation in the sample with the highest yield. To derive the expected value of the best observation in the sample, the n^{th} order statistic and the extreme value statistic is calculated (Gumbel, 1958; Epstein, 1960).

The model that follows is illustrated in terms of the exponential distribution. The exponential distribution is chosen mainly because it provides an explicit and tractable formula for determining the distribution of order statistics.[2] Moreover, the type of research the exponential distribution describes is typified in biological processes or crop research like canola and wheat (e.g., monotonically decreasing probability density function).

In terms of the exponential distribution, the expected value of the increase in yield is (Evenson and Kislev 1976):

$$(7) \qquad E_n(\Delta y) = \sum_{i=1}^{n} \frac{1-[1-e^{-\lambda(y-\theta)}]^i}{\lambda i}$$

Allowing n to be a continuous variable, the sum by integration is:

$$(8) \qquad E_n(\Delta y) = \int_{i=1}^{n} \frac{1-[1-e^{-\lambda(y-\theta)}]^i}{\lambda i}\, di$$

To take the derivative of the change in yield of the exponential distribution with respect to the number of trials, Leibnitz's Rule is applied:

$$(9) \qquad \frac{\partial E_n(\Delta y)}{\partial n} = \frac{1-[1-e^{-\lambda(y-\theta)}]^n}{\lambda n}$$

Note that for the exponential distribution, basic research can affect the parameters λ and θ. The mean of the exponential is $\theta + 1/\lambda$ and the variance is $1/\lambda^2$. Basic research could increase θ thereby increasing the lower bound and the mean of the distribution without affecting variance, or basic research could reduce λ which would simultaneously increase the mean and the variance of the distribution.

Firm *A*'s objective is to choose the number of trials that maximizes its indirect profit function while it considers the cost of the experimentation. Hence, the problem firm *A* faces is:

[1] It is assumed that the decision makers in the private firms are risk neutral,[14] which may accurately reflect the investment behavior of the very large, diversified multinational firms involved in crop research today.

[2] Generally, it is not easy to derive an explicit and tractable formula for the distribution of order statistics (Epstein 1960).

(10) $\underset{n^A}{Max}\ \Pi^A(n) = w^A\psi_i^* - L^*\psi_i - c^A n$,or,

$$\frac{1}{18}\frac{sp[E(\Delta y^A)^2 - 2E(\Delta y^A)E(\Delta y^B) + 6E(\Delta y^A)\tau + E(\Delta y^B)^2 - 6\tau E(\Delta y^B) + 9\tau^2]}{\tau} - c^A n$$

The FOCs for firm *A* and firm *B* are equal to:

(11) $$\frac{\partial\Pi}{\partial n^A} = \frac{1}{3}sp[\frac{\partial E(\Delta y^A)}{\partial n^A}] - c \ = 0\text{, or , }\frac{1}{3}sp[\frac{\partial E(\Delta y^A)}{\partial n^A}] = c$$

(12) $$\frac{\partial\Pi}{\partial n^B} = \frac{1}{3}sp[\frac{\partial E(\Delta y^B)}{\partial n^B}] - c \ = 0\text{, or , }\frac{1}{3}sp[\frac{\partial E(\Delta y^B)}{\partial n^B}] = c$$

Using the exponential distribution, the FOC for firm *A* is:

(13) $$\frac{\partial\Pi}{\partial n^A} = \frac{1}{3}\frac{sp\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A} - c = 0,\text{ or }\frac{1}{3}\frac{sp\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A} = c$$

This condition states that the expected profits from R&D search are maximized when the marginal values of the expected benefits are equal to marginal costs. Finally, the second-order condition (SOC) with respect to the number of trials, hereafter referred to as **H**, is less than zero for maximization problem:

(14) $$\frac{\partial^2\Pi}{\partial n^{A^2}} = -\frac{1}{3}\frac{sp[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]}{\lambda\ n^A} - \frac{1}{3}\frac{sp\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\ n^{A^2}} = \mathbf{H} < 0$$

Results and Discussion

Given the nature of the expression, we were unable to estimate a closed-form solution for n^A. Hence, the Implicit Function Theorem is applied to determine the effect of the exogenous variables on the number of trials the firm is undertaking. The relationship between the exogenous (policy) variable and the optimal level of private research *n* is derived in the form of propositions.

Proposition 1: *A decrease in the marginal cost of experimentation will increase the number of research trials and the private firm's R&D search.*

Proof:

(15) $$\frac{dn^A}{dc} = -\frac{\dfrac{\partial^2\Pi}{\partial n^A\partial c}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{-1}{\mathbf{H}} < 0$$

The denominator of the above comparative static is the SOC of the expected profit maximization and therefore is negative in sign. The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to the cost of the experimentation, which is negative in sign.

Proposition 2: *An increase in the output price (the price that farmers receive for their crop) increases the private firm's R&D search and applied research expenditure.*

Proof:

(16) $$\frac{dn^A}{dp} = -\frac{\dfrac{\partial^2\Pi}{\partial n^A\partial p}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{\dfrac{1}{3}\dfrac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\ n^A}}{\mathbf{H}} > 0$$

Given that 0<e^{-x}<1, and that λ>0, z>0, y>0, then $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$, which results in a numerator that is positive in sign.

Proposition 3: *Basic research that either increases the lower bound or the mean of the potential yield distribution, or that reduces the parameter λ in the exponential distribution, thereby increasing the variance and the mean will increase the number of the private firm's R&D search and applied research expenditure.*

Proof:

$$(17)\quad \frac{dn^A}{d\theta} = -\frac{\frac{\partial^2\Pi}{\partial n^A\partial\theta}}{\frac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{\frac{1}{3}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]}}{\mathrm{H}} > 0$$

$$(18)\frac{dn^A}{d\lambda} = -\frac{\frac{\partial^2\Pi}{\partial n^A\partial\lambda}}{\frac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{\frac{1}{3}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}(-y+\theta)e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]\,\lambda} - \frac{1}{3}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda^2 n^A}}{\mathbf{H}} < 0$$

Proposition 4 *For any given potential yield distribution, a higher current technology level will reduce the private firm's R&D search and applied research expenditure.*

Proof:

$$(19)\quad \frac{dn^A}{dy} = -\frac{\frac{\partial^2\Pi}{\partial n^A\partial y}}{\frac{\partial^2\Pi}{\partial n^{A^2}}} = -\frac{-\frac{1}{3}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}e^{-\lambda(y-\theta)}}{[1-e^{-\lambda(y-\theta)}]}}{\mathbf{H}} < 0$$

Proposition 5: *Applied public research "crowds out" applied private research expenditure -- i.e., an increase in public applied research expenditure reduces the private firm's R&D search and applied research expenditure*[3].

Proof:

Total differentiating the FOC in equation (11) with respect to endogenous n^A and the exogenous n^B and applying the Implicit Function Rule to produce the comparative static derivative dn^A/dn^B, this gives:

$$(20)\frac{dn^A}{dn^B} = \frac{\frac{2p\tau}{18}\frac{\partial E(\Delta y^A)}{\partial n^A}\frac{\partial E(\Delta y^B)}{\partial n^B}}{\frac{2p\tau}{18}E(\Delta y^A)\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}} + \frac{2p\tau}{18}\frac{\partial E(\Delta y^A)}{\partial n^A}\frac{\partial E(\Delta y^A)}{\partial n^A} - \frac{2p\tau}{18}E(\Delta y^B)\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}} + \frac{6p}{18}\frac{\partial^2 E(\Delta y^A)}{\partial n^{A^2}}} < 0$$

Note that the denominator of the above comparative static is negative in sign while the numerator is positive. If we consider a small deviation from the symmetric equilibrium where $E(\Delta y^A)=E(\Delta y^B)$, equation 20 is reduced to $\frac{dn^A}{dn^B} = -\frac{1}{1+3\tau}$. When τ=0, meaning that the two

[3] For this proposition we assume that firms *B* is public while firm *A* is private. The public firm autonomously chooses the level of research investment and the other firm reacts to this increasing expenditure as given by the theoretical model. Once the public firm has made the autonomous research decision, it prices its product in a way similar to private firms as described above. This may be reasonable assumption given that many public institutions sell or give their varieties to private firms for marketing

varieties are identical, then the above equation is equal to $\frac{dn^A}{dn^B}=-1$, which implies that public applied research investment completely "crowds out" private research. However, when τ>0, (the varieties are differentiated) then the ratio $\frac{dn^A}{dn^B}$ is negative but less than one in absolute value. In this case there is an incomplete "crowding out" effect. Consequently, public applied research is a substitute for ("crowds out") applied private research regardless of the degree of product differentiation.

Proposition 6:

(a) An increase in product differentiation τ will not change the private firm's R&D search and applied research expenditure.

(b) When product differentiation τ is increased, the price charged to the farmers is increased, while costs do not increase indicating an increase in the market power of firms.

***Proof*:**

Part (a)

$$(21)\qquad \frac{dn^A}{d\tau}=\frac{\dfrac{\partial^2\Pi}{\partial n^A\partial\tau}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}}=\frac{0}{\mathbf{H}}=0$$

Part (b)

Given that $\frac{dn^A}{d\tau}=0$, then $\frac{\partial E(\Delta y^A)}{\partial\tau}=0$ and $\frac{\partial E(\Delta y^B)}{\partial\tau}=0$, then:

$$(22)\qquad \frac{dw^{A*}}{d\tau}=\frac{\partial w^{A*}}{\partial\tau}=p>0$$

Proposition 7: *An increase in the intellectual property rights will increase the private firm's R&D search and applied research expenditure.*

***Proof*:**

$$(23)\qquad \frac{dn^A}{ds}=-\frac{\dfrac{\partial^2\Pi}{\partial n^A\partial s}}{\dfrac{\partial^2\Pi}{\partial n^{A^2}}}=-\frac{\dfrac{1}{3}\dfrac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A}}{H}>0$$

Proposition 8: *An increase in a firm's market size will increase the private firm's R&D search and applied research expenditure*[4].

***Proof*:**

[4] The theoretical model developed in the previous section was modified to examine this issue. It is assumed that farmers prefer variety *A* to variety *B*, so they are willing to pay more for variety *A* for any given level of Δy^A, Δy^B and w^B and less for variety *B*. Given increased demand for variety *A*, the share of firm *A* is increased which increases the market size of that firm, while the opposite outcome holds for firm *B*. The FOC under this scenario for firm *A* is equal to: $\frac{\partial\Pi^A}{\partial n^A}=\frac{1}{18}\frac{p[2\frac{\partial E(\Delta y^A)}{\partial n^A}E(\Delta y^A)-2\frac{\partial E(\Delta y^A)}{\partial n^A}E(\Delta y^B)+6\frac{\partial E(\Delta y^A)}{\partial n^A}\tau]}{\tau}+\frac{p\frac{\partial E(\Delta y^A)}{\partial n^A}m}{9}+\frac{\frac{\partial E(\Delta y^A)}{\partial n^A}m}{9\tau}-c=0$
where *m* denotes the increase of the producers' willingness to pay for variety *A* and the reluctance of the producers' willingness to pay for variety *B*.

$$(24)\qquad \frac{dn^A}{dm} = -\frac{\dfrac{\partial \Pi^A}{\partial m}}{\dfrac{\partial \Pi^A}{\partial n^A}} = -\left\{ \frac{\dfrac{1}{9}\dfrac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^A}}{A} + \frac{\dfrac{1}{9}\dfrac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\tau\lambda n^A}}{A} \right\} > 0$$

where A is:

$$(25)\qquad \begin{aligned} A = &-\frac{1}{3}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]}{\lambda\, n^A} - \frac{1}{3}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda\, n^{A^2}} - \\ &\frac{1}{9}\frac{p[1-e^{-\lambda(y-\theta)}]^{n^A}\ln[1-e^{-\lambda(y-\theta)}]m}{\lambda\, n^A} - \frac{1}{9}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}m}{\lambda\, n^{A^2}} - \\ &\frac{1}{9}\frac{[1-e^{-\lambda(y-\theta)}]^{n^A}\}\ln[1-e^{-\lambda(y-\theta)}]m}{\tau\lambda\, n^A} - \frac{1}{9}\frac{\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}m}{\tau\lambda\, n^{A^2}} \end{aligned}$$

Note that the denominator of the above comparative static A for both fractions is the SOC of the expected profit maximization and is therefore negative in sign. The numerator of the above expression represents the change in the marginal benefit of the research investment with respect to m. Given that $0<e^{-x}<1$, and that $\lambda>0$, $z>0$ and $y>0$, then $0 < 1-[1-e^{-\lambda(y-\theta)}]^{n^A} < 1$, and the numerator of both fractions are positive in sign. Hence, the sign of the comparative static is positive.

Policy Implications of the Derived Propositions

A number of policy implications can be drawn. The first point to make is that, for a given potential yield distribution there is diminishing returns to experimental search process used to find the highest yielding variety. This was shown with *Proposition 4*, where the higher the current technology level (or research findings), the lower the intensity of the private R&D search, since the probability of inventing a better variety is reduced. Consequently, research into new crops may be more profitable than into well-established ones.

We also showed with *Proposition 2* that the output price positively affects the number of trials. An increase in the area of crop would have the same effect as an increase in the price of the product and would increase the amount of private investment in research. This also suggests that low-value crops and those grown on small areas would attract little private research funding.

Moreover, basic research is required to maintain the profitability of applied research given that applied research is a search process. Eventually, the current technology level will reach a point where further search is no longer economically viable. Therefore, for applied research to remain profitable in the long run, basic research is required to create new distributions.

Furthermore, it was shown that while, applied public research "crowds out" applied private research (*Proposition* 6) the opposite holds true for basic public research (*Proposition* 3). Hence, these propositions suggest that where a private research industry exists, the public sector should shift resources from applied to basic research. This will increase the pace of innovation and research outcomes.

A combination of the "crowd out" proposition and the *Proposition 1*, which shows a negative relationship between marginal cost of experimentation and number of research trials, has implications for the type of support given to the research industry. Specifically, government policies that reduce the cost of research –e.g., per unit subsidy increase private investment in R&D. Conversely, public policies that compete with the private sector –e.g., public firms invest in applied research -- would “crowd out” private research investment. Consequently, subsidy may be more effective means to increase applied private R&D investment.

The analysis also reveals an interesting dynamic feedback effect between market size and R&D intensity. A firm with a market size advantage will do more research. By applying more effort to each approach to innovation, the probability of success also rises, which increases the expected value of the yield change and causes an even greater market share. In turn, this allow to crowds firm with smaller market share out of existence, which ultimately results in a concentrated industry with fewer research products. If one goes beyond the scope of our analysis to consider variety *A* and *B* as different crops, then private investment in a large crop will tend to crowd out the research and production of smaller crops. Hence, this finding is in favor of large-scale firms, which supports Schumpeter’s hypothesis.

Finally, the increase in appropriability of research benefits via IPRs could have a significant effect on the R&D intensity and welfare implications. An increase in IPRs, while stimulating research investment will leave producers worse off because they will then pay higher prices for varieties. From the social welfare perspective, policy makers have to be aware of the trade-off between overall efficiency and producer welfare. It should be noted, however, that the above analysis assumes that both varieties *A* and *B* will exist in the presence of incomplete IPRs, which may not be the case. If private research firms are unable to reap sufficient returns to pay for the fixed cost involved in research, they may not invest at all which would leave farmers conceivably worse off.

Private Investment vs Socially Optimal Investment

In this section we examines whether the R&D investment derived in the imperfectly competitive model is the socially optimal. In a case where a given number of trials or R&D search result in a variety with a higher yield than the current one, the input demand curve shifts to the right. The welfare implications of a demand shift can be measured in the associated factor market (in the seed market) without considering the other input markets (Moschini and Lapan 1997).

The objective function of a social welfare maximizer[5] can be determined as a product of the input market producer surplus of farmers who cultivates variety *A*, the farmers who cultivate variety *B,* and the producer surplus of breeding firm *A* and breeding firm *B*:

$$(26)\ SW = \left[\tau\psi_i^* - w^A\psi_i^* - \frac{\tau\psi_i^{*2}}{2} + pE(\Delta y^A)\psi_i^*\right] + \left[pE(\Delta y^B)(1-\psi_i^*) - w^B(1-\psi_i^*) + \frac{\tau}{2} - \frac{\tau\psi_i^{*2}}{2}\right] + \left[w^A\psi_i^* - L\psi_i^* - cn^A\right] + \left[w^B(1-\psi_i^*) - L(1-\psi_i^*) - cn^B\right]$$

Differentiating the social objective function with respect to n^A, n^B, and ψ_i^*, and after algebra manipulations gives:

$$(27)\quad \frac{\partial SW}{\partial n^A} = \frac{1}{2}p\frac{\partial E(\Delta y^A)}{\partial n^A} - c = 0 \Rightarrow \frac{1}{2}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A} = c$$

$$(28)\quad \frac{\partial SW}{\partial n^B} = \frac{1}{2}p\frac{\partial E(\Delta y^B)}{\partial n^B} - c = 0 \Rightarrow \frac{1}{2}\frac{p\{1-[1-e^{-\lambda(y-\theta)}]^{n^B}\}}{\lambda n^B} = c$$

$$(29)\quad \psi_i^* = \frac{1}{2}$$

[5] The objective of the social planner is to maximize total economic surplus, which can be translated to social welfare if and only if all individuals have equal welfare weights and each has a same marginal utility of income.

Consequently, the investment is socially optimal only when above conditions hold.

The marginal conditions for the privately optimal number of trials differ from the conditions for social optimum, resulting in under investment by the private sector. Specifically, the private marginal benefit of a research trial for firm *A* (as shown before) equal to $\frac{1}{3}\frac{sp\{1-[1-e^{-\lambda(y-\theta)}]^{n^A}\}}{\lambda n^A}$. The ratio of private firm marginal benefits to social marginal benefits is therefore equal to 2/3*s*. Given that 0≤ s ≤ 1, the private research firm marginal benefits are strictly less than the social benefits. The result is under investment relative to the social optimal.

The reason for the under investment is that when firms invest in research, some of the benefits spillover to farmers as demand for the improved product shifts outward. Because the research firm making the investment in research cannot capture the increase in surplus going to the buyers of their product (in this case farmers), their private marginal benefit from research is less than the social marginal benefit. As a result the firms under invest relative to the social optimum.

The under-investment problem is exacerbated when IPRs are not fully enforceable (s <1). In the extreme case when s=0 no economic rent can be extracted from farmers and there will be no private incentives to invest. Given that research firms are only concerned with their private benefits from an R&D investment and not of any the spillover effects that their action may have on others, they will under-invest in R&D relative to the socially optimum.

Summary and Conclusion

In this paper we model important characteristics of today's research industry. Many changes took place in the R&D industry including, the introduction of improved IPRs and biotechnology, the increase private investment, and many mergers and acquisitions within the research industry. The implications of these changes are not well understood despite a large body of related literature.

In order to examine the private incentives on R&D and the spillovers of knowledge (private vs public, and basic vs applied research), we developed a three stage stochastic/imperfectly competitive framework. This model is characterized by a small number of firms developing and selling differentiated products to heterogeneous producers. Agricultural research is modeled with explicit recognition of the search process, which allows us to recognize research as a stochastic process with sporadic outcomes and to explicitly model the interaction between basic and applied research.

The findings of this study are mainly in the form of propositions. Basic public research "crowds in" applied private research while applied public research "crowds out" applied private research. The current technology level and the cost of the experimentation negatively affect private investment, while the price of the final product positively affects the private investment. Moreover, the greater the product heterogeneity, the higher the price charged with the same amount of R&D. Finally, the increase in the appropriability of IPRs and the firm's market size all increase the private firm's R&D investment.

We showed that there are inadequate incentives to invest relative to the social optimum, even with complete enforceable IPRs. Without first-degree price discrimination, the research firms had to share some of the benefits of research output with the producers purchasing their variety. As a result they underinvest relative to the social optimum. The private underinvestment is exacerbated when property rights are incomplete. The study also draw a number of policy implications including a potential role for subsidization of research to address the under investment.

References

Adams, J.D. 1990. "Fundamental Stocks of Knowledge and Productivity Growth." *Journal of Political Science* 98(4): 673-702.

Alston, J.M., and R.J. Venner. 2000. *The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement.* EPTD Discussion Paper No.62.

Alston, J.M., M.C. Marra, P.G. Pardey and T.J. Wyatt. 2000. *Research Returns Redux: a Meta-Analysis of the Returns to Agricultural R&D.* EPTD Discussion Paper No.38.

Bergstrom, T., L. Blume, and H. Varian. 1986. "On the Private Provision of Public Goods." *Journal of Political Economy* 29: 25-49.

Brooks, H. 1994. "The Relationship between Science and Technology." *Research Policy* 23: 477-486.

Dasgupta, P., and P.A. David. 1994. "Toward a New Economics of Science." *Research Policy* 23: 487-521.

David, P.A., B.H. Hall, and A.A. Toole. 1999. "Is Public R&D a Complement or Substitute for Private R&D? A review of the Econometric Evidence." A report prepared for a special issue of *Research Policy*. Cambridge, MA: National Bureau of Economic Research.

Epstein, B. 1960. "Elements of the Theory of Extreme Values." *Technometrics* 2: 27-41.

Evenson, R.E., and Y. Kislev. 1976. "A Stochastic Model of Applied Research." *Journal of Political Economy* 84: 265-281.

Fulton, M., and D. Giannakas. 2000. *The Effects of Biotechnology on Concentration and Structure in the Agricultural Inputs Industry*. A discussion paper prepared for Agriculture and Agri-Food Canada. University of Saskatchewan, Department of Agricultural Economics: Saskatoon, SK.

Fulton, M.E. 1997. "The Economics of Intellectual Property Rights: Discussion." *American Journal of Agricultural Economics* 79: 1592-1594.

Griliches, Z. 1986. "Productivity, R&D, and Basic Research at the Firm Level in the 1970's." *The American Economic Review* 76(1): 141-154.

Gumbel, E.J. 1958. *Statistics of Extremes*. New York: Columbia University Press.

Huffman, W.E. and R.E. Evenson. 1993. *Science for Agriculture: A Long-Term Perspective*. Ames: Iowa State University Press.

Lesser, W. 1998. "Intellectual Property Rights and Concentration in Agricultural Biotechnology." *AgBioForum* 1: 56-61.

Lindner, R. 1999. "Prospects for Public Plant Breeding in a Small Country." Presented at the ICABR Conference, "The Shape of the Coming Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective." University of Rome, "Tor Vergata," Rome and Ravello, June 17-19.

Moschini, G., and H. Lapan. 1997. "Intellectual Property Rights and the Welfare Effects of Agricultural R&D." *American Journal of Agricultural Economics* 79: 1229-1242.

Nelson, R.R. 1970. "Information and Consumer Behavior." *Journal of Political Economy* 78: 311-329.

Pannel, D.J. 1999. "On the Balance between Strategic-Basic and Applied Agricultural Research." *The Australian Journal of Agricultural and Resource Economics* 41(1): 91-113.

Pavitt, K. 1991. "What Makes Basic Research Economically Useful?" *Research Policy* 20: 109-119.

Rausser, G. 1999. "Public/Private Alliances." *AgBioForum* 2(1): 5-10.

Roberts, R.D. 1984. "A Positive Model of Private Charity and Public Transfers." *Journal of Political Economy* 92:136-148.

Romer, P. 1990. “Endogenous Technological Change.” *Journal of Political Economy* 98(2): S71-S102.
Rosenberg, N. 1990. “Why Do Firms Do Basic Research (With Their Own Money)?” *Research Policy* 19(2): 165-174.
Rosenberg, N. 1991. “S&T Interfaces.” *Science and Policy* 18(6): 335-346.
Steinberg, R. 1993. “Does Government Spending Crowd Out Donations? Interpreting the Evidence.” In *The Nonprofit Sector in the Mixed Economy*, Avner Ben-Ner and Benedetto Gui, eds., Ann Arbor: University of Michigan Press, 99-125.
Stigler, G.J. 1961. “The Economics of Information.” *Journal of Political Economy* 69: 213-225.
Thirtle, C., P. Bottemley, P. Palladino, D. Schimmelpfennig, and R. Townsend. 1998. “The Rise and Fall of Public Sector Plant Breeding in the United Kingdom: A Casual Chain Model of Basic and Applied Research and Diffusion.” *Agricultural Economics* 19: 127-143.
Warr, P.G. 1982. “Pareto Optimal Redistribution and Private Charity.” *Journal of Public Economics* 19: 131-138.