THE DISTRIBUTIONAL EFFECTS OF PRIVATE SECTOR R&D MANAGEMENT: IN-HOUSE AND AT PUBLIC INSTITUTIONS*

Douglas D. Parker

University of California, Berkeley

David Zilberman

University of California, Berkeley[1]

ABSTRACT

This paper compares alternative mechanisms for research and development of new or improved inputs. The research alternatives considered include producer control and finance, producer control and government finance, and monopolistic input manufacturer control and finance. This final alternative includes the control and finance of university research by the private sector.

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[1] Douglas D. Parker is an Assistant Cooperative Extension Specialist, Department of Agricultural and Resource Economics, University of California, Berkeley; David Zilberman is a Professor, Department of Agricultural and Resource Economics, University of California, Berkeley.

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Private sector sponsored research at public institutions has been increasing over the past two decades. Industry now sponsors between 16 to 24 percent of university based research in biotechnology (OTA, 1988). Approximately 46 percent of biotechnology firms support some biotechnology research at universities (OTA, 1988). Some universities have signed agreements to allow first refusal of new patents in exchange for partial private financing. According to the Office of Technology Assessment study, 41 percent of the companies investing in university-based research have derived trade secrets from that work. Increased private sector financing and control of research could lead to a decrease in total research expenditures and a shift in the emphasis of research. This paper extends the literature on the optimal level of publicly funded R&D to include privately funded R&D.

Empirical evidence indicates that expenditures on public research in agriculture differ from social welfare maximizing levels. Ruttan suggests that political economic considerations, rather than pure efficiency considerations, determine the allocation of resources for public research and may explain its underprovision. Ruttan's insights spawned a new body of literature aimed at investigating distributional effects of alternative assumptions concerning control of R&D. de Gorter and Zilberman derive political decision rules for public provision of R&D under alternative assumptions regarding control and finance of research by producers or consumers. Their model considers three options. 1) Producers control R&D while taxpayers finance it. 2) Producers control and finance R&D. 3) Government sets socially optimal levels of R&D while taxpayers finance it. The final institutional setup depends on properties of the technology and elasticities of supply and demand of the final product. de Gorter, Nielson and Rausser, and Rausser and Foster, expand the framework to analyze joint determination of public R&D, and input and output subsidies to agricultural producers.

Maximizations of weighted sums of consumer and producer surpluses, where weights reflect political power, drive the models mentioned above. Furthermore, the models consider situations where the alternative to public research is no research. This literature ignores the possibility of the provision of R&D by the private sector. Private sector R&D can be either in-house or through contractual agreements with public institutions. While appropriate for many unshielded innovations such as new agronomical practices, ignoring the private sector's influence and contributions toward R&D is inappropriate for shielded innovations such as new varieties or hybrids. A technology is shielded when it can be protected in such a manner that it cannot be inexpensively reproduced by others in the same economic markets.

This paper extends the de Gorter and Zilberman model for shielded innovations to include the possibility of the provision of R&D to create a new input by a monopolistic input manufacturer. This R&D could physically take place in private or public sector labs. The key elements are that the private sector fund and control the research. Benefits from research results accrue to the private firm through a monopoly of the new input. In the case of research at a public facility, control may be obtained through exclusive patenting agreements. The paper identifies circumstances under which each of these arrangements is probable and shows that each scenario is likely to lead to underinvestment in research, when compared to the social optimum. Thus, there is justification for public research even when the expected result is a shielded innovation. The extent of underinvestment and distribution of benefits vary substantially depending on economic parameters of the input and output markets, the technology, and who controls the R&D.

The Model

The R&D process introduces a new input to the industry. Denote the amount of the new input used in production by X. The new input may be a yield-increasing variety, a disease-resistant variety, a pesticide, etc. It reduces the amount spent on existing inputs in production of the output. Let $C(Y, X)$ denote cost of existing inputs as a function of output and the new input. The cost function is a reduced form equation with implicit prices.

When V is price paid by the producer for the new input, the cost of producing Y units of output using X units of the new input is $C(Y, X) + VX$. Assume marginal costs are positive and increasing with output. Costs of existing inputs decline with the use of the new input, $C_x < 0$. At $X = 0$, the marginal reduction in costs associated with the new input is large but finite and the marginal reduction in cost is decreasing in absolute value ($C_{xx} \geq 0$). Thus, for a given output level, the availability of the new input reduces costs of existing inputs by $C(Y, X) - C(Y, 0)$, but requires an additional expenditures of VX to purchase the new input. Assume that costs of existing inputs are concave functions in Y and X, and that use of the new input reduces marginal costs of existing inputs ($C_{yx} < 0$). Therefore, increases in the employment of the new input, ceteris paribus, shifts competitive supply to the right. This is consistent with previous studies of R&D that view new technologies as causes of competitive supply shifts (Alston, Edwards and Freebairn; Lindner and Jarrett), and with studies of the impacts of introducing or canceling inputs such as pesticides (Lichtenberg, Parker, and Zilberman).

Assume consumers derive utility (measured in monetary terms) from consumption of output, $U(Y)$. The analysis here uses surplus measures for welfare analysis with $U(Y)$ essentially denoting an area under the (*compensated*) demand curve. Production of the new input uses a constant returns to scale technology with cost per unit denoted by $R(I)$, where I is research expenditures. Assume that costs decline with research expenditures at a decreasing rate ($R_I < 0$, $R_{II} > 0$), and that the cost of producing new inputs with no research expenditures is prohibitively high ($R(0) = \infty$).

Social Optimum

Our analysis consists of comparisons of outcomes under alternative scenarios. Table 1 contains the optimization problems and the resulting optimality conditions under each scenario. The social optimization problem (T.3) maximizes the difference between benefits of consumption and costs of production. Equation (T.4) requires output markets to be competitive. Equation (T.5) requires the marginal benefits from the use of the new input to equal its unit cost. The condition for optimal R&D investment (T.6) requires that the value of marginal product of research expenditure—marginal reduction in unit cost times input use—equals one unit of expenditure. At the social optimum, output price P^1 is equal to marginal benefit U_y and marginal cost of output C_y, while input price V^1 is equal to unit cost $R(I)$ and its marginal benefit C_x.

Producer Organizations Control and Finance Research/Results are Public

Firms operating in competitive markets may cooperate in controlling and financing research on public goods. In agriculture, producers' associations often finance university research that leads to lower input costs. Such research may create improved varieties, pest control strategies, etc. In this case, producers determine resource allocation by maximizing their joint net profits (revenues minus input costs and research expenditures) where anti–trust laws constrain input and output markets to be competitive. Thus, the profit maximization problem becomes that shown by (T.7). Equation (T.8) gives the condition determining optimal investment (we omit the elements of the functions for simplicity).

Let $y = D^y(P)$ denote output demand, $y = S^y(P, V)$ output supply, and $x = D^x(P, V)$ input demand. Let $ED_p^y = D_p^y \, P/Y$ denote price elasticity of demand, and denote output price elasticity of output supply by $ES_p^y = S_p^y \, P/Y$, with other elasticities being defined similarly. Dividing the numerator and denominator of the second–term of the left–hand side of (T.8) by $C_{yy}C_{xx} - C_{yx}^2$ and letting $D_p^y = 1/U_{yy}$ denote the slope of the output demand curve, $S_p^y = C_{xx}/\left(C_{xx}C_{yy} - C_{yx}^2\right) \geq 0$ and $S_v^y = C_{yx}/\left(C_{yy}C_{xx} - C_{yx}^2\right) < 0$ the marginal effects of prices on supply, and $D_p^x = -\,C_{yx}/\left(C_{yy}C_{xx} - C_{yx}^2\right) > 0$ and $D_v^x = -\,C_{yy}/\left(C_{yy}C_{xx} - C_{yx}^2\right) < 0$ the marginal effects of prices on input demand, and noting that $D_p^x = -S_v^y$, yields

(1) $$\frac{-R_I}{V}\left\{XV + PY\frac{ES_v^y}{ES_p^y - ED_p^y}\right\} = 1.$$

Equation (1) states that, when producer organizations control and finance research, marginal producers' benefits equal marginal expenditures. The left–hand side (LHS) of (1) shows that the marginal benefit to producers from research expenditures consists of the difference between the marginal reduction in input costs and marginal revenue losses. Increases in research expenditures reduce input prices, leading to an expanded output supply, which leads to an output price decrease. The input price elasticity of output supply, and supply and demand elasticities of output are key parameters in determining the producer marginal loss of income from expenditures (the second term in the LHS of (1)).

Let Y^2, X^2, and I^2 denote optimal outcomes when producer organizations control and finance research. Since their marginal benefits from research are smaller than social benefits, expenditures will be below the social optimum when producers control and finance research. Thus, comparison of producers' control and finance of research to the social optimum yields; $I^2 \le I^1$, $Y^2 \le Y^1$, $X^2 \le X^1$, $P^2 \ge P^1$, $V^2 \ge V^1$.

For the sake of simplicity, we present optimizations as unconstrained decision choice problems. From the producers' perspective, it may be optimal to have no research at all. This case occurs when both output price elasticities of demand and supply are small, and output is responsive to variable input use. Recall that $D_p^x = -S_v^y$. Then, at $I^2 = 0$, $ED_p^x/(ES_p^y - ED_p^y) > 1$. In this case public research will benefit consumers by reducing output price. Ruttan and Schultz argue that the public finances agricultural research mostly in industries with low price elasticities of demand, when the major beneficiaries of resulting increases in supply are consumers. Growers finance and control much of the research in specialty crops—vegetables and fruits—with relatively high output price elasticities.

Producer Organizations Control and Consumers Finance Research/Results are Public

As in the previous case, assume that product and input markets are competitive; however, under the arrangements considered here, producers do not finance the research.

Thus, the determination of optimal research funding differs as shown in (T.9) and (T.10). Following the procedure used to derive (1), determination of optimal research becomes

$$(2) \qquad -R_I X\left[1-\frac{ED_p^x}{ES_p^y - ED_p^y}\right] = \frac{-R_I}{V}\left\{XV + PY\frac{ES_v^y}{ES_p^y - ED_p^y}\right\} = 0.$$

Equation (2) implies investment until the marginal benefit to producers is equal to zero. Outcomes are denoted by Y^3, X^3, and I^3. Output, input use, and investment are likely to be greater than or equal to the case when producers control and finance research ($Y^3 > Y^2$, $X^3 \geq X^2$, $I^3 \geq I^2$), while output and input prices are lower ($P^3 \leq P^2$, $V^3 \leq V^2$).

When producer organizations control but do not finance research, there may still be an underprovision of research and an undersupply of output and input relative to the social optimum. Equations (T.6) and (2) show that the condition for $I^3 < I^1$ is that, at the social optimum ($I = I^1$), $-R_I X^3\left[ED_p^x/\left(ES_p^y - ED_p^y\right)\right] > 1$. Situations such as these occur when the final product is a commodity with an inelastic demand and low output price elasticity of supply, price elasticities are declining with output, and the new input shifts supply substantially. Even when research under producer optimum is smaller than under social optimum ($0 < I^3 < I^1$), the well being of consumers, B (a measure of consumer surplus), is improved by the introduction of public research, $Y^1 > Y^3 > Y^0$, and $B^1 > B^3 > B^0$. As long as consumers' welfare is greater than in the case of no public R&D, consumers may not object to publicly financed agricultural research even when research management is "captured" by producers.

Conditions (T.6) and (2) imply that overprovision of research is possible when producers control research and consumers pay for it. This will occur if, at the socially optimal outcome ($I = I^1$), $-R_I X^3\left[ED_p^x/\left(ES_p^y - ED_p^y\right)\right] < 1$. In these situations, producers face elastic demand or elastic supply. Producers benefit a great deal from research in such situations, while consumers do not get much from the research they finance. There is not much evidence of overprovision of public research, so this appears to be more of a theoretical possibility. It may be that consumers block the establishment of public–financed research efforts controlled by producers in situations where consumer welfare may not benefit from the research because of elastic demand. In these situations, public research could be financed cooperatively by producers or the research could be conducted by a private enterprise that will act as a monopoly in the input market.

Monopolistic Input Manufacturers Control and Finance Research/Results are Private

This scenario applies to research performed both in-house and in public institutions when the private sector controls the research agenda, finances the research, and controls the use of the research results. Through patenting and rights of first refusal to exclusively license patents, the private sector can control benefits from R&D and allow for academic publication. In the past most private research in agriculture has been performed in-house, in the mechanical and chemical areas. However, with the introduction of hybrids and more protective seed property rights laws, private companies are playing a major role in researching new crop varieties. Biotechnology research focuses on genetically engineered varieties resistant to pests, herbicides, and diseases. These varieties represent new inputs, and the economics of their development can be assessed by viewing the behavior of the monopolistic input manufacturer.

Since the final product is produced by a competitive industry, input price is equal to marginal benefit from the input, $-C_x(Y, X)$. The competitive equilibrium in the final product market sets a constraint where marginal cost of the final product is equal to marginal utility. Thus, the solution to the constrained optimization problem (T.11), determines optimal behavior of the input manufacturer. Output, input, and research levels are denoted by Y^4, X^4, and I^4. Equation (T.12) determines input use. At the optimal level of research expenditure, the value of marginal product of research expenditures–reflected by lower input product costs–is equal to marginal expenditure (T.13).

When the input manufacturer is a monopolist, there is a difference between the input's price ($V = -C_x$), and its cost of production (R). This wedge is a product of input use and the term $Z = \left[\left(U_{yy}C_{xx}\right) - C_{yy}C_{xx} + C_{yx}^2\right]/(U_{yy} - C_{yy})$. To interpret this term note that $-1/Z$ is the total marginal input price effect on input use taking into account output price adjustment to input price change. Specifically, consider the case when output is determined by the market–clearing relationship $U_y = C_y(Y, X)$, and the industry is input price taking so that $-C_x(Y, X) = V$. Total differentiation of these market–clearing relationships yields total marginal effects of input price on input use and output,

$$(3)\quad T_v^x = -\frac{U_{yy} - C_{yy}}{U_{yy}C_{xx} - (C_{yy}C_{xx} - C_{yx}^2)} = -\frac{1}{Z} < 0, \text{ and } T_v^y = \frac{-C_{yx}}{U_{yy}C_{xx} - (C_{yy}C_{xx} - C_{yx}^2)} < 0.$$

The total marginal effect of input price on input use T_V^X, differs from marginal input demand $D_v^x = -C_{yy}/(C_{yy}C_{xx} - C_{yx}^2)$, which is the marginal change in input use in response to input price *when output price is given.* Using (3), total price elasticity of input use is defined as $ET_v^x = T_v^x V/X < 0$. Introducing this definition and $V = -C_x$ to (T.12), determination of input use becomes

$$(4)\qquad V\left[1 + \frac{1}{ET_v^x}\right] = R(I^4).$$

Equation (4) relates price and marginal cost of inputs when produced by a monopolist in a way that is similar to the standard behavior rule of a monopoly. When a monopoly manufactures an input, the ratio of the price–marginal cost wedge to price is the inverse of total price elasticity of input. The only difference between the optimal resource allocation condition and the resource allocation rule when a monopolist input manufacturer controls research is in the determination of the optimal level of new input use. Comparison of conditions (T.5) and (4) shows that less input, research expenditures, and output result when an input manufacturing monopolist controls and finances research than under the social optimum. The gap between the social optimum and the input manufacturer's optimum increases when total price elasticity of input is smaller (in absolute value).

The total effect of a change in input price on input use incorporates the effects of two basic relationships- demand and cost functions of the final product. A better understanding of resource allocation when a monopolistic input manufacturer controls research requires an understanding of the impacts of key parameters of these basic relationships on input use. Define $EMC_y = C_{yy}\, Y/C_y$ as the elasticity of marginal cost of output. By dividing the numerator and denominator of the second element of the LHS of (T.12) by X and introducing $C_y = P$, $-C_x = V$, and the elasticity notation, the condition for determination of input use becomes

$$(5) \qquad V\left[1+\frac{1}{ED_v^x}\frac{ES_p^y - ED_p^y}{EMC_y^{-1} - ED_p^y}\right] = R(I^4).$$

In the standard model of monopoly behavior, the wedge between price and marginal cost is equal to price divided by elasticity of demand. Equation (5) suggests that this does not hold in the case of a monopolistic input manufacturer. Let J denote the wedge, then from (5),

$$(6) \qquad J = V - R(I^4) = -\frac{V}{ED_v^x}\cdot G, \text{ where } G = \frac{ES_p^y - ED_P^y}{EMC_y^{-1} - ED_p^y}.$$

When the value of G differs from 1, properties of demand and supply for the final product affect the wedge between price and marginal cost of a monopolistic input manufacturer. Since $S_p^y = [C_{yy} - (C_{yx}^2 / C_{xx})]^{-1} \geq C_{yy}^{-1}$ and, hence, $ES_p^y \geq EMC_y^{-1}$; $G \geq 1$. Thus, the wedge between price and marginal cost of input is larger (in absolute value) than input price divided by its demand elasticity. This suggests the monopolistic input manufacturer recognizes that an increase in input use reduces demand price of the input—

not only because of movements along the input demand curve but also because of a shift of the demand curve resulting from a lower output price.

The analysis shows that when a monopolistic input manufacturer controls research, both features of demand for the final product, as well as features of the cost function contribute to the reduction in input use and, hence, output and R&D activities will be below the social optimum. While producer organizations will finance the optimal level of research when demand is infinitely elastic, to take advantage of negative input demand, a monopolistic input manufacturer will underfinance research even when output demand is infinitely elastic. Thus, producers' control and finance leads to greater levels of research than control by a monopolist input manufacturer.

Implications and Extensions

The benchmark for evaluating public research strategies is what happens without public research. For unshielded innovations the benchmark is no R&D. In this paper we also consider shielded innovations and expand the benchmark from the no public R&D case to include the possibility of research controlled and funded by the private sector. We show that in most cases there is likely to be underinvestment in research. Producers control and taxpayer finance of research results in more research effort than when producers control and finance research. But even this last arrangement yields a greater research effort than monopolistic input manufacturer control and finance of research. The results suggest that increased private control and finance of research at public institutions may lead to an overall decline in total research. Furthermore, because such privately financed research may lead to increased patenting and other forms of intellectual property rights protections, is has the potential to shift the research focus of these public institutions.

The results suggest that curtailing public research efforts while developing laws that allow privatization of research leading to generation of these inputs (e.g., patent laws on seed varieties), will result in underinvestment in research and reductions in social welfare. Furthermore, these results seem to reflect unfavorably with the reality of infrequent joint research efforts financed by producer organizations and the increasing prevalence of research, in-house and at public institutions, funded and controlled by input manufacturers who gain from monopolistic status (through patents for instance).

The analysis thus far assumes operation in a closed economy. In closed economies, public research will be higher in cases without input manufacturers than in cases with input manufacturers (and patent like protections). Input manufacturer solutions may result in more R&D in open economies with technology exports. Situations where output manufacturers operate in a closed economy while input manufacturers exist in an open economy allow for producer and private sector cooperation in R&D. For example, if output is perishable with no imports from other regions it may be optimal for producers in any given region to fund research since this will not increase competition from the outside. If the innovation is usable in other regions then there will also be an incentive for the private sector to develop the innovation. This type of arrangement could lead to increased levels of investment through producer/private sector cooperation. The analysis suggests that movement to free trade may reduce the gain from public sector research on shielded innovations. Free trade may shift public research from research on generic problems to research on specific problems.

The analysis of input manufacturers and their R&D activities under the existing patent system abstracts away from many important issues addressed elsewhere in the literature including uncertainty and the possibility of "races" between manufacturers in the research of new products (for an excellent review of the patent race issue see Tirole, Chapter 10). While such "races" are very important elements of agricultural behavior, there are many situations where input manufacturers concentrate on different "niches", each aiming at a specific product that will provide it with monopoly power during the patent life.

It seems that biotechnology firms tend to follow the latter route and specialize, producing a relatively small number of "races."

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Table 1. Comparison of Optimal Outcomes Under Different R&D Management Scenarios

Management Scenario	Optimization Problem	First Order Conditions
No R&D/Output Market Competitive, No Input Market	(T.1) $\max_{Y} U(Y) - C(Y,0)$	(T.2) $U_y(Y^0) = C_y(Y^0,0)$
Social Optimum/Results Public/All Markets Competitive	(T.3) $\max_{Y,X,I} U(Y) - C(Y,X) - R(I)X - I$	(T.4) $U_y(Y^1) = C_y(Y^1,X^1)$ (T.5) $-C_x(Y^1,X^1) = R(I^1)$ (T.6) $-R_I(I^1)X = 1$
Producers Control and Finance Research/Results Public/All Markets Competitive	(T.7) $\max_{I} U_y(Y)Y - C(Y,X) - R(I)X - I$ s.t. $U_y(Y) - C_y(Y,X) = 0$ $-C_x(Y,X) - R(I) = 0$	(T.8) $-R_I\left\{X + \frac{U_{yy}\ Y\ C_{yx}}{C_{yx}^2 + C_{xx}(U_{yy} - C_{yy})}\right\} = 1$
Producers Control and Consumers Finance Research/Results Public/All Markets Competitive	(T.9) $\max_{I} U_y(Y)Y - C(Y,X) - R(I)X$ s.t. $U_y(Y) - C_y(Y,X) = 0$ $-C_x(Y,X) - R(I) = 0$	(T.10) $-R_I\left\{X + \frac{U_{yy}\ Y\ C_{yx}}{C_{yx}^2 + C_{xx}(U_{yy} - C_{yy})}\right\} = 0$
Monopolistic Input Manufacturers Control and Finance Research/Results Private/Output Market Competitive, Input Market Monopolistic	(T.11) $\max_{X,I} -C_x(Y,X)X - R(I)X - I$ s.t. $U_y(Y) - C_y(Y,X) = 0$	(T.12) $-C_x - X\left\{\frac{C_{xx}U_{yy} - C_{yy}C_{xx} + C_{yx}^2}{U_{yy} - C_{yy}}\right\} = R(I^4)$ (T.13) $-R_I(I^4)X = 1$