THE ROLE OF MARKET STRUCTURE IN AGRICULTURAL BIOTECHNOLOGY INVESTMENT AND PRODUCTION

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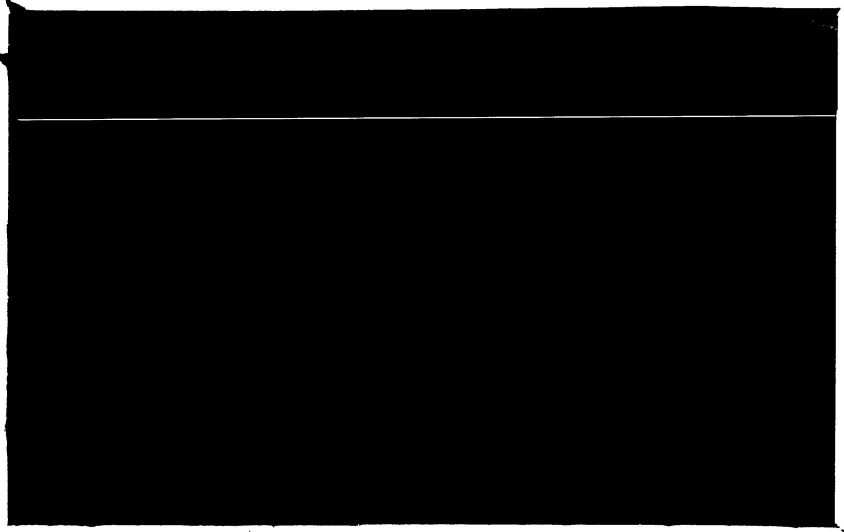

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ABSTRACT

Biotechnology enables rapid development of products with specific characteristics. This paper shows that who controls the direction of biotechnology development influences the resulting industry structure. Through economies of intermarket control (economies of scope in demand), chemical companies develop productive inputs that increase dependence on chemicals whereas nonchemical companies tend toward development of inputs that substitute for chemicals. Chemical companies tend to both under invest and under produce. Conversely, firms without vested chemical interests tend to over invest and over produce -- even given monopoly enabling patents. Results are developed which show how the resulting industry structure is a consequence of the choice of agricultural policy.

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I. INTRODUCTION

Until recently biology has been largely a descriptive science. It is now rapidly becoming a synthetic science. According to one industry official,[1]

> "The development of biotechnology is as revolutionary to the science of biology as the development of quantum mechanics during the early 1900s was to physics and as the development of synthetic organic chemicals was for chemistry in the mid-1800s. This is a true scientific revolution and will have the same kind of major economic impacts on society as synthetic chemicals and quantum mechanics has had."[1]

Agriculture is expected to experience some of the strongest impacts of biotechnology. Public discussion and noneconomic literature raises a number of questions about these new technical developments. As Doyle [1985] points out, the new biological "instruments" create the possibility of "designer inputs." That is, agricultural inputs can be produced to fit a particular market niche. As a result, public concern has been expressed about who will control the direction and development of these new biological inputs.

Examples of products now being investigated include insect and disease resistant plants, plants which can directly fix nitrogen and hence eliminate the need for nitrogen fertilizer, and plants that are resistant to currently used herbicides. All of these products will be produced using modern molecular biological techniques and controlled in the market through the sale of seeds with the genetic characteristics. Thus, all major seed companies as well as many independent biotechnology firms are involved in biotechnology research and are part of the biotechnology industry (Goldburg, et al., [1990]). However, questions about the organization of the agricultural biotechnology industry have arisen because of the rapid trend toward the acquisition of small independent biotechnology companies by major U.S. chemical corporations and because of the focus of biotechnology research among these companies. For example, Doyle [1985] reports that more than 120

American Seed Trade Association companies have become subsidiaries of major chemical corporations since the late 1960s. Of the 56 members of the National Council of Plant Breeders, 20 are subsidiaries of major petrochemical corporations.

These trends raise questions such as the following. Will these joint chemical/biotechnology firms produce more or less biotechnology inputs than would be produced by separate chemical and biotechnology firms? Will the investment of joint firms be socially efficient? Will investment be in the same biotechnology products as would separate firm investment? Should policy changes be considered which will change the economic environment and induce the development of a different industry structure? This paper investigates these questions by developing a two-market model where economies of scope occur through demand relationships (traditional economies of scope occur through cost savings in production). A simple two-period model is developed to explore production and investment decisions in the biotechnology and chemical industries under alternative market structures. Specifically, investment and production is compared between cases where biotechnology is or is not controlled by the chemical industry. Each of the cases are also compared to the social optimum. Then some implications about the likely evolution of the biotechnology and chemical industries are drawn for alternative technological and policy scenarios.

II. INSTITUTIONAL ENVIRONMENT OF THE BIOTECHNOLOGY AND CHEMICAL INDUSTRIES

For the purposes of this paper, the agricultural chemical industry is defined as the industry producing traditional commercial fertilizers and pesticides for agricultural input markets. Because of the great diversity of tools and techniques employed and the similarities of products, an all inclusive definition of biotechnology is more difficult. Most molecular biologists agree that biotechnology includes genetic manipulation, embryo manipulation and transfer, cell culture, monoclonal antibodies, and bioprocess engineering. It differs from traditional technologies in speed, precision, and reliability. But rearrangements are possible through genetic engineering that cannot be made by nature, e.g., insertion of a human gene into livestock. For the purposes of this paper, biotechnology is simply equated to genetic engineering. This is the area where most policy questions have arisen.

The institutional structure facing the biotechnology and chemical industries is largely dictated by government regulations and patent law. Patents for chemicals confer monopoly power on individual firms for particular chemical products. Most Western countries provide patents on agricultural chemicals with patent lives from 15 to 20 years. Patents facilitate an agricultural chemical industry that is heavily oriented toward research and development with research expenditures amounting to 16 percent of total sales in the U.S. (Office of Chemicals and Allied Products, [1985]). This compares to 4.8 percent for all chemicals and allied products, 10.3 percent for professional and scientific instruments, and 17.5 percent for aircraft and missiles. (The latter two are the highest industry groups reported for 1985 in the *Statistical Abstract of the United States.*) Levin, et al. [1984] find that the agrichemical industry ranks near the top among a wide range of industries in patent effectiveness as a means of appropriating the benefits of research and development. Appropriability is crucial in inducing development of new agricultural chemicals which, in turn, increase productivity of agriculture. Rapid product development makes older products obsolete quickly so that most sales occur under monopolistic patent protection. Although prices beyond the patent period are much lower, proprietary sales have been roughly three times nonproprietary sales. Also, even though hundreds of agrichemicals are marketed at a given time, most of the sales have been concentrated in a handful of products with distinct purposes. As a result, the agricultural chemical industry is highly concentrated with a U.S. four-firm concentration ratio of 65 percent and eight-firm ratio of 84 percent (Office of Chemicals and Allied Products, [1985]).

While similar descriptive statistics do not yet exist for the biotechnology industry, government policy is developing along similar lines. Patents for seeds (created by the 1970 Plant Variety Protection Act) and genetically modified organisms (since the 1980 Supreme Court decision in Diamond versus Chakrabarty) grant monopoly power to biotechnology companies. While many small biotechnology companies initially sprang up, the development of commercially feasible technologies to date suggests the emergence of a handful of large scale (patented) successes with a similarly concentrated industry.

Several alternative explanations are possible for the acquisition of biotechnology companies by the chemical industry. One is cost related economies of scope as emphasized in the modern theory of industrial organization. Economies of scope may occur through sharing of production facilities or human capital associated with market development and regulatory approval. The determination of industry structure by economies of scope has been heavily researched (Baumol, Panzar, and Willig, [1982]). Some of this work focuses on the implications for interindustry behavior. For example, Bulow, Geanakoplos, and Klemperer examine the case where a firm's behavior in one market affects competitors behavior in a second market because of related changes in its marginal costs in the second market. The Bulow, et al., results depend critically on whether goods are strategic substitutes or complements. Cost related interdependencies, however, do not appear to be the major consideration for the problem of this paper since many small agrichemical companies have successfully competed in small fringe markets while bearing these costs.

Another more plausible explanation is economies of intermarket control. Some of the potential products of the biotechnology revolution are strong substitutes for existing agricultural chemicals and will likely displace chemical markets. Other potential products are strong complements with existing agricultural chemicals and can be used by chemical companies to enhance their markets (Chemical Week, [1982]). For example, insect resistant plants and nitrogen fixing plants are substitutes for currently used pesticides and fertilizers while herbicide resistant plants such as glyphosate resistant tomatoes complement herbicide use by allowing farmers to reduce expensive hoeing labor. To illustrate the importance of these considerations, of the eight major chemical companies which account for 70 percent of pesticide sales worldwide, all are supporting research on herbicide resistance while only one has a substantive research program on insect resistance.

This paper considers the case where demand effects in one market occur because of developments affecting behavior in another. Complementarity and substitutability considerations paralleling those of Bulow, et al., are shown to be important when interdependence occurs through equilibrium demand relationships (rather than through production costs as in their case). Furthermore, these considerations are shown to be important in fostering alternative industry structures rather than simply affecting behavior with a given structure.

To examine these possibilities, three alternative market structures are compared: (1) two monopolies selling in separate markets that are related in demand, (2) one monopoly that sells in both markets, and (3) the social optimum (competition in both markets). To do this, a methodology is developed for comparative static analysis of alternative market structures. This is done by parameterizing market structures as points in a continuum thus facilitating conventional comparative static methods. Many studies examine the behavior of individual market structures but comparisons of market structures are relatively few. For the most part, comparisons of market structure are limited to simple cases without multiple related markets (e.g., comparison of monopoly or competition with various forms of duopoly and oligopoly in a single market). The methodology used here facilitates comparison of market structures in more complex problems when a suitable parameterization can be found.

The results identify cases where production and investment beyond the social optimum can occur even given monopoly power. Different market structures are found to tend toward faster development of different types of biotechnology products. Thus, a socially preferred mix of biotechnology development may be more likely if some development is controlled by chemical companies with other development in the hands of independent biotechnology (or seed) firms. In most cases, production and investment are closer to the social optimum under the industry structure that tends to be attracted to develop a particular biotechnology input. The important characteristic in this distinction is whether the biotechnology product is a complement or substitute in demand with a chemical product. Finally, the paper demonstrates how agricultural policy, which alters the demand elasticity for agricultural products, affects the cross elasticity of demand for agricultural inputs and thus tends to determine chemical/biotechnology industry structure.

III. THE STRUCTURE OF THE BIOTECHNOLOGY AND CHEMICAL INDUSTRIES

Consider two alternative market structures. In the first, a chemical input for agriculture is produced by an industry that does not enter the biotechnology industry. Development and production of a related biotechnology input for agriculture are done by a separate biotechnology industry. Both have a monopoly in sales through patents. In the second case, the chemical industry produces a chemical input for agriculture but also undertakes development and production of the related biotechnology input. The industry has a monopoly in sales of both chemical and biotechnology products through patents. Outcomes under each of these cases will be compared to the social optimum which corresponds to competitive sales under either structure after socially optimal investment.

Suppose production is divided into two time periods for purposes of considering investment. Chemical production in each period has restricted cost function $g(Y,K)$ where Y is quantity of chemicals and K is capital employed in the chemical industry ($g_k < 0$, $g_y > 0$, $g_{yy} > 0$, $g_{yk} < 0$). Capital depreciates at rate δ. Any investment C to improve productive capacity in the second time period must occur in the first time period.

No biotechnology productive capacity exists initially. In the first period, the firm decides whether to incur a given investment cost of I to develop a new product and production facilities. The investment decision must be undertaken before properties of the product such as environmental safety are known. After investment expenses are incurred, the biotechnology industry faces probability $1 - \rho$ that production will be banned for environmental reasons. If investment is undertaken, production costs of the biotechnology product follow the restricted cost function $h(X,\psi)$ in the second period where X is the quantity produced and $\psi = 0$ under a ban and $\psi = 1$ without a ban [$h_x > 0$, $h_{xx} > 0$, $h_\psi < 0$, $h_{\psi x} < 0$, $h(0, \psi) = 0$].

Suppose equilibrium demand for chemical and biotechnology inputs by agriculture (considering agricultural output price adjustments) is represented in price-dependent form as $u \equiv u(X,Y)$ and $v = v(X,Y)$ where u is the price of the biotechnology product and v is the price of the chemical input. It can be shown for a competitive agricultural industry with concave production function and downward sloping output demand function that $u_x v_y - u_y v_x > 0$, $u_Y = v_X$, and u_Y and v_X are opposite in sign to the cross elasticities of the quantity-dependent equilibrium demand for chemical and biotechnology inputs. Hence, $u_y = v_x > 0$ implies biotechnology and chemicals are equilibrium complements in demand while $u_y = v_x < 0$ implies equilibrium substitutes.

The problem of the biotechnology/chemical industry can be represented by the second period production problem,

$$\pi^*_{2\psi} = \max_{X_2 \geq 0; Y_2 \geq 0} \pi_{2\psi} \equiv \theta X_2\, u(X_2,Y_2) + \phi Y_2\, v(X_2,Y_2) - \theta h(X_2,\psi\lambda) - \phi g(Y_2,K_2), \quad (1)$$

the first period production problem,

$$\pi^*_1 = \max_{Y_1 \geq 0} \pi_1 \equiv \phi Y_1\, v(0,Y_1) - \phi g(Y_1,K_1) - \theta\lambda I - \phi C, \quad (2)$$

and the first period investment problem,

$$\max_{C \geq 0; \lambda=0,1} \bar{\pi} = \bar{\pi}\,(C,\lambda;\theta,\phi) = \pi^*_1 + \frac{1}{1+r}\left[\rho\pi^*_{21} + (1-\rho)\pi^*_{20}\right] \quad (3)$$

where $K_2 = (1-\delta)K_1 + C$, r is the discount rate, and λ is a decision variable for biotechnology investment ($\lambda = 1$ with investment, $\lambda = 0$ without). Note that (1), (2), and (3) can be solved recursively following Bellman's optimality principle to characterize optimal production and investment over the two period time horizon. The cost function $h(X_2,\psi\lambda)$ is assumed to make production expenses prohibitive in the second period if the biotechnology product is banned ($\psi = 0$) or investment does not occur ($\lambda = 0$).

The problems in (1), (2), and (3) include the following special cases:

(i) the separate biotechnology industry ($\theta = 1$, $\phi = 0$),

(ii) the separate chemical industry ($\theta = 0$, $\phi = 1$),

(iii) the joint biotechnology/chemical industry ($\theta = 1$, $\phi = 1$).

The social optimum is also examined with $\theta = 1$ and $\phi = 1$ by taking u and v as given. This corresponds to optimal public funding of research with competitive industry behavior after product development. However, the social optimum does not correspond to a private competitive solution since private research would not be undertaken to develop a biotechnology product without assurance that research costs could be recovered, e.g., by patents.

IV. BIOTECHNOLOGY AND CHEMICAL INDUSTRY PRODUCTION BEHAVIOR

Consider first investigation of production behavior under alternative industry structures assuming investment in the biotechnology industry has already taken place. This is done by analyzing problem (1) assuming that a ban on biotechnology production does not occur. For simplicity, all subscripts representing time period or biotechnology ban are suppressed in this section and the next. In the case of two separate industries each with monopoly power, behavior is assumed to follow Nash equilibrium.

First order conditions in the case of separate industries are $u_x X + u - h_x = 0$ for the biotechnology industry ($\theta = 1$, $\phi = 0$); $v_y Y + v - g_y = 0$ for the chemical industry ($\theta = 0$, $\phi = 1$); and $v_x Y + u_x X + u - h_x = 0$ and $u_y X + v_y Y + v - g_y = 0$ for the case of the joint industry ($\theta = 1$, $\phi = 1$). By comparison, the social optimum is characterized by $u - h_x = 0$ and $v - g_y = 0$.

To avoid repetition, all three sets of conditions are represented by

$$\pi_x \equiv u_x X\mu + v_x Y\nu + u - h_x = 0, \quad \pi_y \equiv u_y X\nu + v_y Y\mu + v = g_y = 0 \qquad (4)$$

where $\mu = 1$, $\nu = 0$ for separate biotechnology and chemical industries; $\mu = 1$, $\nu = 1$ for a joint biotechnology/chemical industry; and $\mu = 0$, $\nu = 0$ for the social optimum. The second order conditions are examined in Appendix A.

The case of separate industries can be compared with the joint industry case by total differentiation of (4) with respect to ν holding u = 1,

$$\frac{dX}{d\nu} = \frac{1}{D}(\pi_{xy} u_y X - \pi_{yy} v_x Y) = -\frac{u_y}{D}(\pi_{yy} Y - \pi_{xy} X) \qquad (5)$$

$$\frac{dY}{d\nu} = \frac{1}{D}(\pi_{yx} v_x Y - \pi_{xx} u_y X) = -\frac{u_y}{D}(\pi_{xx} X - \pi_{yx} Y). \qquad (6)$$

By derivation, $\pi_x = MR(X) - MC(X)$ and $\pi_y = MR(Y) - MC(Y)$ so $\pi_{xx} = \partial[MR(X) - MC(X)]/\partial X$, $\pi_{yy} = \partial[MR(Y) - MC(Y)]/\partial Y$, $\pi_{xy} = \partial MR(X)/\partial Y$, and $\pi_{yx} = \partial MR(Y)/\partial X$ where MR and MC represent perceived marginal revenue and marginal cost of the respective products in each case. Thus, when chemicals and biotechnology are equilibrium substitutes (complements), a joint biotechnology/chemical industry produces less (more) of a biotechnology product than separate industries if the effect of chemical sales on the marginal profit of chemical production weighted by chemical production is less than on the marginal profit of biotechnology production weighted by biotechnology production [note that $\partial MC(X)/\partial Y = \partial MC(Y)/\partial X = 0$]. However, the role of substitution in ranking biotechnology production under the two industry structures is just reversed if the relationship of the weighted marginal profit effects is reversed. Similarly, when chemicals and biotechnology are equilibrium substitutes (complements), a joint industry produces less (more) chemicals than separate industries if the effect of biotechnology on the marginal profit of biotechnology production weighted by biotechnology production is less than on the marginal profit of chemical production weighted by chemical production; the role of substitution again reverses if the relationship of weighted marginal profit effects is reversed.

To understand the likely implications of these results consider first the case where biotechnology and chemicals are equilibrium complements. Since complementarity implies an increase in biotechnology (chemical) production increases the chemical (biotechnology) price that can be charged ($u_y = v_x > 0$), this would likely also be true of marginal revenues, i.e.,

$$\pi_{xy} = \frac{\partial MR(X)}{\partial Y} > 0, \qquad \pi_{yx} = \frac{\partial MR(Y)}{\partial X} > 0. \tag{7}$$

Use of (7) in (5) and (6) implies $dX/d\nu > 0$, $dY/d\nu > 0$ if $u_y > 0$. Thus, the joint industry likely produces more of both biotechnology and chemicals than separate industries with a complementary demand relationship.

An example with positive cross marginal revenue effects is provided by the constant elasticity formulation,

$$u(X,Y) = AX^{\beta-1}\,Y^{\gamma}, \qquad v(X,Y) = BX^{\beta}\,Y^{\gamma-1}, \qquad \alpha B = \gamma A, \tag{8}$$

where $0 < B < 1$ and $0 < \gamma < 1$ for the case of complementary inputs [note that the parametric relationships in (8) are required by $u_y = v_x$]. From (8), one can verify that cross marginal revenue effects satisfy (7) and that

$$\pi_{xy} = \nu\gamma^2 \frac{u}{y} + \mu\beta^2 \frac{v}{X} + \beta(1 - \mu) \frac{v}{X}, \qquad \pi_{yx} = u\gamma^2 \frac{u}{Y} + \nu\beta^2 \frac{v}{X} + \gamma(1 - \mu) \frac{u}{Y}$$

which are positive by complementarity. Thus, the joint industry produces more than separate industries under complementarity following (5) and (6).

This result is contrary to the usual result that increased monopolization restricts output. The result is explained by noting that a joint industry has incentive to take advantage of the increased profitability that production of each good implies for the other under complementarity.

Next, consider the implications of the results when biotechnology and chemicals are equilibrium substitutes. Here, the results depend on the relative magnitudes of production. The joint industry may produce with less or more of either biotechnology or chemicals than separate industries. However, the joint firm will not produce more of both since from second order conditions $X(\pi_{xx} X - \pi_{yx} Y) + Y(\pi_{yy} Y - \pi_{xy} X) < 0$ (see Appendix A).

The alternatives in this case can be illustrated by a linear example with

$$u(X,Y) = u_0 + u_x X + u_y Y, \qquad v(X,Y) = v_0 + v_x X + v_y Y \tag{9}$$

where for the moment u_x, u_y, v_x, and v_y are constants. Here the cross marginal revenue effects are positive (negative) as $u_y = v_x > (<) 0$ so substitution implies negative cross effects in marginal revenue as well as demand. Thus, the signs of (5) and (6) are indeed indeterminate. Considering the weighted marginal profit effects as in (5) and (6) implies

$$\frac{dX}{d\nu} \gtreqless 0 \text{ as } \varepsilon_x^v (1 + \nu) \lesseqgtr \varepsilon_y^v (1 + u) - g_{yy} \frac{Y}{v} \tag{10}$$

$$\frac{dY}{d\nu} \gtreqless 0 \text{ as } \varepsilon_y^u (1 + \nu) \lesseqgtr \varepsilon_x^u (1 + u) - h_{xx} \frac{X}{u} \tag{11}$$

where $\varepsilon_x^v = v_x X/v$, $\varepsilon_y^v = v_y Y/v$, $\varepsilon_y^u = u_y Y/u$, and $\varepsilon_x^u = u_x X/u$.

The result in (10) implies that if the slopes of marginal costs are bounded, then the joint industry produces more chemicals and less biotechnology than separate industries when the own price flexibility of chemicals is sufficiently greater (in absolute value) than the cross price flexibility of chemicals with respect to biotechnology. Intuitively, this corresponds to the situation where chemical demand is sufficiently more inelastic than biotechnology demand and substitution (the cross elasticity) is high.[2] This result is in sharp contrast to the textbook case of unrelated demands where a single firm discriminates by exploiting the more inelastic demand with a higher price while "dumping" in the market with more elastic demand. This result is plausible because the joint industry will expand the demand it can exploit more. If the demand for chemicals is more inelastic, it can be exploited more (by high pricing). Chemical demand can be expanded by reducing biotechnology sales, so the joint industry tends to restrict biotechnology sales even though it faces more elastic demand. This situation tends to occur when X is small relative to Y. In other words, when a chemical industry controls the development of a biotechnology that substitutes for chemicals, it is more likely to restrict the release of biotechnology when the biotechnology industry is small.

The result in (11) suggests that the joint industry produces less chemicals and more biotechnology than separate industries when the own price flexibility of biotechnology is sufficiently smaller than the cross price flexibility of biotechnology with respect to chemicals. Intuitively, this is associated with chemical demand less elastic than biotechnology demand. This case is less plausible for a small biotechnology industry because demand elasticity is believed to increase with product age.

V. PRODUCTION BEHAVIOR WITH SOCIAL OPTIMALITY

Consider next the comparison of production under each industry structure to the social optimum. The case of separate industries can be considered by comparative static analysis of (4) with respect to μ where $\nu = 0$,

$$\frac{dX}{d\mu} = -\frac{1}{D}\left[\pi_{yy}\, u_x\, X - \pi_{xy}\, v_y\, Y\right], \qquad \frac{dY}{d\mu} = \frac{1}{D}\left[\pi_{yx}\, u_x\, X - \pi_{xx}\, v_y\, Y\right]. \tag{12}$$

Again the qualitative effects pivot on the effects of production on marginal profits but now the weights are the products of price flexibilities and prices (e.g., $u_x X = \varepsilon^u_x u$) rather than quantities. The implications of these results are not stated in their full generality here because such statements are lengthy and not very insightful. Rather the implications for several intuitively appealing special cases are examined.

If biotechnology and chemicals are equilibrium complements in demand, use of (7) and (12) reveals $dX/d\mu < 0$ and $dY/d\mu < 0$. Thus, separate industries produce socially suboptimal levels of both products. If the products are unrelated in demand, this is the usual result that monopolies restrict market quantities. Here market quantities are further contracted because the restrictive behavior of each monopoly reduces demand for the other's product.

In the case of substitutes, separate industries may produce either more or less than the social optimum but not more of both. To see this, note from Appendix A that $u_x X(\pi_{yy} u_x X - \pi_{xy} v_y Y) - v_y Y(\pi_{yx} u_x X - \pi_{xx} v_y Y) < 0$. Using this in (12) reveals that $dX/d\mu < 0$ or $d\mu < 0$ or both since $u_x, v_y < 0$.

To examine the individual alternatives, consider again the linear demand system in (9). Substitution in (12) obtains $dX/d\mu \gtreqless 0$ as $\varepsilon^u_y (1 + \nu)v_y \gtreqless \varepsilon^u_x [(1 + \mu) v_y - g_{yy}]$ and similarly for $dy/d\mu$. Thus, separate industries produce more (less) biotechnology than the social optimum if the own price flexibility of biotechnology is sufficiently small (large) absolutely relative to the cross price flexibility of biotechnology with respect to chemicals. Intuitively, this is the case where biotechnology demand is sufficiently more (less) elastic than chemical demand and substitution is high.[3] The intuition of this result is separate industries tend to exploit (contract) the market with more inelastic demand while the other market tends to expand beyond the social optimum because of cross demand effects. A similar result whereby duopoly tends to over produce was obtained by Bulow, et al.

Considering linearity, these results can also be written as $dX/d\mu \gtreqless 0$ as $Y/X \gtreqless [v_y (1 + \mu) - g_{yy}]/[u_y v_y (1 + \nu)] > 0$ and similarly for $dY/d\mu$. Thus, the relationship of biotechnology production with separate industries to the social optimum depends on the relative production levels. Separate industries produce more (less) biotechnology than the social optimum if chemical production is sufficiently large (small) relative to biotechnology production, i.e., the biotechnology industry tends to produce beyond the social optimum if the biotechnology industry is sufficiently small, e.g., in its infant stages. Similarly, the chemical industry tends to produce beyond the social optimum if the biotechnology industry is large. This suggests that the chemical industry will try to "hang on" too long if biotechnology becomes dominant.

While the result that one of the monopolistic industries over produces seems counterintuitive, the intuition can be made clear for the case of perfect substitutes as in Figure 1. Total demand for two perfect substitutes is represented by D in either panel. With Nash equilibrium, the demand perceived by the first firm is $D - q_2$ where q_2 is the amount produced by firm 2. The associated marginal revenue curve is MR_1 and leads to production q_1 with marginal cost schedule MC_1. Similarly, firm 2 faces demand $D - q_1$ and marginal revenue MR_2 and produces q_2 with marginal cost schedule MC_2. Consistent with perfect substitution, both firms charge the same price p. The social optimum is determined where the horizontal summation of marginal costs, ΣMC_i, intersects total demand. In Figure 1, this occurs below the minimum of the first firm's marginal cost and implies firm 1 should not produce at all while firm 2 should expand production to q_2'. To see that this type of result is more likely to occur with smaller scale production by firm 1, note that the vertical difference, ab, in $D - q_2$ and MR_1 gets smaller with smaller scale cost structure for firm 1 (i.e., as the marginal cost curve moves above and left of MC_1). Hence, the smaller the small firm (in equilibrium) the more likely the case of over production.

Consider next the relationship of production with a joint industry to the social optimum. To do this, let $\gamma \equiv u \equiv \nu$ and consider total differentiation of (4) with respect to γ,

$$\frac{dX}{d\gamma} = -\frac{1}{D}\,[\pi_{yy}\,(u_x X + u_y Y) - \pi_{xy}\,(v_x X + v_y Y)] \tag{13}$$

$$\frac{dY}{d\gamma} = \frac{1}{D}\,[\pi_{yx}\,(u_x X + \mu_y Y) - \pi_{xx}\,(v_x X + v_y Y)]. \tag{14}$$

For the case of complements, use of (7) in (13) and (14) obtains

$$\frac{dX}{d\gamma} \gtreqqless 0 \text{ and } \frac{dY}{d\gamma} \gtreqqless 0 \text{ as } \varepsilon^u_x + \varepsilon^u_y \gtreqqless 0 \text{ and } \varepsilon^v_y + \varepsilon^v_x \gtreqqless 0. \tag{15}$$

From this result, it is only clear that the joint firm under produces both products if cross price flexibilities are dominated by own flexibilities. If the cross price flexibility dominates the own flexibility (say, $-\varepsilon^x_y < \varepsilon^v_x$) and the cross effect on the marginal profitability sufficiently dominates the own effect (say, $\pi_{xy} >> -\pi_{yy}$) for one of the goods, then possibly both are over produced. If cross price flexibilities just offset own flexibilities, then the joint monopolistic industry produces at the social optimum.[4]

A definite result is obtained for the case of complements with constant elasticity demands. Use of (8) obtains $u_x X + u_y Y = v_x X + v_y Y = \beta + \gamma - 1$. Also, $u_x v_y - u_y u_x < 0$, $u_x < 0$, and $v_y < 0$ implies by negative definiteness

$$[X \quad Y] \begin{bmatrix} u_x & u_y \\ v_x & v_y \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} = X(u_x X + u_y Y) + Y(v_x X + v_y Y) < 0.$$

Combining these two equations obtains $\varepsilon^u_x + \varepsilon^u_y = \frac{1}{u}(u_x X + u_y Y) < 0$ and $\varepsilon^v_y + \varepsilon^v_x = \frac{1}{v}(v_x X + v_y Y) < 0$. Thus, from (15) the joint firm under produces both products. Recalling results of the previous section, this implies a clear welfare ordering of the two industrial organizations of this paper. With demand complements, separate industries produce less of both goods than a joint industry which produces less of both than the social optimum. Thus, a joint industry operates closer to the social optimum than separate industries. This occurs because the greater ability to capture positive cross effects on demand entices the joint industry to give up some monopoly restriction.

Next consider the case where biotechnology and chemicals are substitutes in demand. A joint industry would never over produce both products in this case since by second order conditions (see Appendix A),

$$(u_x X + u_y Y)\ [\pi_{yy}(u_x X + u_y Y) - \pi_{xy}(v_x X + v_y Y)]$$
$$- (v_x X + v_y Y)[\pi_{yx}(u_x X + u_y Y) - \pi_{xx}(v_x X + v_y Y)] < 0,$$

and $v_x X + v_y Y < 0$, $u_x X + u_y Y < 0$. Thus, from (13) and (14) either $dX/d\gamma <$ 0 or $dY/d\gamma < 0$ or both. Beyond this result, few conclusions are possible for the comparison of the joint firm to the social optimum with substitutes. Apparently, unusual curvature in demands can cause the joint firm to over produce one product or the other. However, with linearity in demands, the joint firm clearly under produces both. That is, use of (9) in Appendix A expressions for π_{xx}, π_{yy}, π_{xy}, and π_{yx} and substitution in (13) with $\gamma \equiv u \equiv \nu$ obtains $dX/d\gamma = - (1/D)\ [(1 + \gamma)(u_x v_y - u_y v_x)X - g_{yy}(u_x X + u_y Y)] < 0$ and, similarly, $dY/d\gamma < 0$ from (14). These results are plausible because substitution would tend to cause a joint monopolist to contract production to exercise greater monopoly power in related markets.

To summarize the results to this point, the most likely relationships are as follows. With equilibrium complements, both separate and joint industries produce less of both goods than the social optimum and separate industries produce less of both goods than a joint industry. This is the case, for example, with constant elasticity demands. With equilibrium substitutes, a good produced in sufficiently small quantity relative to the other is over produced by separate industries and under produced by a joint industry while the other good is under produced by both (more so by separate industries). This is the case, for example, with linear demands.

VI. INVESTMENT IN THE CHEMICAL INDUSTRY: THE ROLE OF EXISTING CAPITAL

To examine whether a high existing capital stock in the chemical industry will reduce investment and production in biotechnology under alternative market structures, differentiate (4) with respect to chemical capital, K,

$$\frac{dX}{dK} = -\frac{1}{D}\pi_{xy}\, g_{yk} \gtreqless 0 \text{ as } \pi_{xy} \gtreqless 0. \tag{16}$$

Higher capital accumulation (higher prior investment and lower depreciation) in the chemical industry results in higher (lower) sales of biotechnology when the effect of chemical sales on the marginal revenue of biotechnology is positive (negative). These results are plausible since the sign of π_{xy} tends to turn on whether chemicals and biotechnology are equilibrium complements or substitutes. With complements, higher previous investment in the chemical industry causes higher current chemical production which causes higher demand for biotechnology. On the other hand, with substitutes, the concerns of under production of biotechnology because of high prior investment in the chemical industry appear to have theoretical basis (because higher chemical production causes lower demand for biotechnology). The one exception is the case of separate industries with equilibrium substitutes where biotechnology is over produced relative to the social optimum if chemical production is sufficiently large relative to biotechnology production.

Next, consider the effect of industry structure and prospects for biotechnology development on investment in the chemical industry. To address these effects, turn to the problem in (3). For brevity, analysis of the first period production problem in (2) is omitted because the results are the same as for (1). The problem in (3) can be considered in two steps: first, chemical investment given the biotechnology investment decision, λ, and second, biotechnology investment given optimal chemical investment (next section). By the envelope theorem, the first order condition for the first step is $\bar{\pi}_c = -\phi\left[1 + \frac{\rho}{1-r} g_k^1 + \frac{1-\rho}{1-r} g_k^0\right] = 0$ where $g_k^\psi \equiv g_k(Y_{2\psi}, K_2)$ and $Y_{2\psi}$ is the value of Y that attains the optimum $\pi_{2\psi}^*$ in problem (1). The effects of industry structure on first-period investment in the chemical industry can be determined by total differentiation of this first order condition which reveals $dC/d\nu = \bar{\pi}_{c\nu}/\bar{\pi}_{cc}$, $dC/d\mu = \bar{\pi}_{c\mu}/\bar{\pi}_{cc}$, and $dC/d\gamma = \bar{\pi}_{c\gamma}/\bar{\pi}_{cc}$.

To evaluate these results, note that $\bar{\pi}_{cc} < 0$ by second order conditions and

$$\bar{\pi}_{ci} = -\phi\left[1 + \frac{\rho}{1-r} g_{yk}^1 \frac{dY_{21}}{di} + \frac{1-\rho}{1-r} g_{yk}^0 \frac{dY_{20}}{di}\right], \quad i = \nu, \mu, \gamma \tag{17}$$

where $g_{yk}^\psi \equiv g_{yk}(Y_{2\psi}, K_2)$. Thus,

$$\frac{dC}{di} \gtreqless 0 \text{ as } \frac{dY}{di} \gtreqless 0, \quad i = \nu, \mu, \gamma. \tag{18}$$

These results are plausible since they imply that more investment in the chemical industry is undertaken under the same market structures that attract more chemical production. Since the indirect effect of first-period investment on second period production is positive, the indirect effects are consistent with the direct effects in both the first and second periods so the overall results in the problem in (1)-(3) are the same as already discussed.

VII. INVESTMENT IN BIOTECHNOLOGY

This section considers conditions under which alternative industry structures tend to be induced and compares the private tendency to invest with the social optimum. This is done by comparing $\bar{\pi}(C^*,\lambda;\theta,\phi)$ in (3) with $\lambda = 0$ and $\lambda = 1$ where C^* is the optimal investment in the chemical industry given the biotechnology investment decision, $C^* = C^*(\lambda,\theta,\phi)$. If $\bar{\pi}(C^*,1;\theta,\phi) >(<) \bar{\pi}(C^*,0;\theta,\phi)$, then biotechnology investment is (not) undertaken. Thus, a factor z tends to induce (discourage) biotechnology investment if $(\partial/\partial z)[\bar{\pi}(C^*,1;\theta,\phi) - \bar{\pi}(C^*,0;\theta,\phi)] > (<) 0$ for $z = \rho, K_1, \nu, \mu, \gamma$. More particularly, this condition holds if $\bar{\pi}_{\lambda z} > (<) 0$ for λ in the unit interval. To use this approach, note first by the envelope theorem that $\bar{\pi}_{\lambda} = -\theta I - \theta\rho\, h_{\psi}(X_{21}, \lambda)/(1 - r)$ where $h_{\psi}(X, \psi) = \partial h/\partial\psi$ since $X_{20} = 0$ and $h(0, \psi) = 0$. Thus, $\bar{\pi}_{\lambda\rho} = -\theta h_{\psi} / (1 - r) > 0$, so that an increase in the probability of not banning the product tends to induce biotechnology investment. Similarly, $\bar{\pi}_{\lambda k1} = -[\theta\rho/(1 - r)]\, h_{\psi x}\, dX_{21}/dK_1 \gtreqless 0$ as $\pi_{xy} \gtreqless 0$. Thus, according to intuitive expectations, higher existing chemical capital tends toward biotechnology investment in the case of complements where (7) holds while it tends away from investment in the case of substitutes where $\pi_{xy} < 0$ (as with linearity).

To examine the effects of industry structure, note that $\bar{\pi}_{\lambda i} = -[\theta\rho/(1 - r)]\, h_{\psi x}\, dX_{21}/di$, $i = \nu, \mu, \gamma$. These results are plausible since they imply that biotechnology investment tends to be undertaken under the same market structures that attract more biotechnology production in the event of investment and no ban.

Because a joint industry tends more toward investment in biotechnology in the case of complements, the results suggest that development of complementary biotechnology products will tend to be controlled by chemical companies that will restrict the release of biotechnology relative to the social optimum (although not as much as would separate biotechnology companies). On the other hand, the initial development of substitute biotechnology products will tend to be controlled by separate biotechnology companies that will over invest. As the biotechnology industry matures (with larger X), production may lag behind the social optimum and chemical industries may have an increased incentive to gain control.

From the point of view of the designer prospects of biotechnology, these results imply that chemical companies will attempt to design complementary biotechnology products while independent biotechnology companies will tend to design biotechnology products that substitute for chemicals. Preservation of monopoly interests may explain the more limited activity whereby chemical companies have bought the rights to biotechnology products developed by independent biotechnology companies in the latter case.

VIII. THE ROLE OF AGRICULTURAL POLICY IN DETERMINING INDUSTRY STRUCTURE

Many of the results in this paper hinge on the signs of cross derivatives of equilibrium demands which determine whether chemicals and biotechnology are equilibrium substitutes ($u_y = v_x < 0$) or complements ($u_y = v_x > 0$). It can be shown that if chemicals and biotechnology are competitive in production (Ferguson, [1969], p. 71), or input substitutability in production (Ferguson, [1969], p. 148) exceeds the absolute final demand elasticity for agricultural products, then chemicals and biotechnology are equilibrium substitutes. Alternatively, if chemicals and biotechnology are complements in production and input substitutability in production is less than the absolute demand elasticity for agricultural products, then chemicals and biotechnology are equilibrium complements.

Several observations are of interest in this context. First, many agricultural products face highly inelastic demand. This tends to make the conditions for equilibrium substitution (complementarity) in input demand equivalent to conditions for competitiveness (complementarity) of inputs in production. This is particularly true for food grains and milk in free markets. On the other hand, government price support programs tend to make the demand for agricultural products elastic which reduces equilibrium substitution in input demand possibly replacing it with complementarity (if the absolute demand elasticity for agricultural products becomes large relative to input substitutability). These results illustrate the need to consider the implications of agricultural policy as well as patent policy with respect to the type of biotechnology industry structure that will be fostered by the current institutional environment. If strong agricultural price supports tend toward equilibrium complementarity, then chemical companies are induced to take over development of biotechnology products and thus restrict biotechnology development below the social optimum. Relaxation of price supports, on the other hand, tends toward equilibrium substitution which tends to encourage development of independent biotechnology companies with biotechnology development stimulated beyond the social optimum at least initially.

IX. CONCLUSIONS

This paper extends the concept of economies of scope to demand side considerations. Specifically, by examining economies of market control, the paper demonstrates that some of the concerns raised with regard to the developing biotechnology industry are well founded. The results show that control of biotechnology development by chemical companies tends in most cases to lead to lower investment and slower release than is socially optimal. However, this industry structure tends to occur for biotechnology products that complement chemicals in demand. The case of substitutes tends to lead to separate biotechnology firms (at least initially when smaller market penetration is envisaged). The solution to suboptimum pursuit of biotechnology in the case of complements is not to induce a separate biotechnology industry structure through institutional control (e.g., not granting biotechnology patents to chemical companies) since a separate industry structure results in even further restriction of the markets.

For the case of substitutes, separate biotechnology firms may be attracted to invest and produce beyond the social optimum. This can occur because of demand interactions whereby a chemical industry that is exploiting a more inelastic chemical demand curve induces over investment and production of biotechnology substitutes. In this case, making changes in the patent or licensing system that tend to induce a joint chemical/biotechnology industry may tend to a more efficient result (for cases where the joint industry under produces less than a separate biotechnology industry over produces).

The policy implications of the latter possibilities are surprising and contrary to arguments advanced by biotechnology industry proponents. That is, since chemical companies are attracted to develop complements which are then under invested and produced, the implications are that chemical industry development of complements should be encouraged. Alternatively, in cases where separate biotechnology industries are attracted to develop substitutes which are then over invested and produced, the implications are that development of substitutes by separate biotechnology firms should be discouraged. The applicability of the latter conclusion, however, requires empirical information that is not yet available. For example, over investment in biotechnology substitutes clearly holds only under linearity of demand and where anticipated market size is sufficiently small relative to chemicals. These are empirical issues. Perhaps in the initial stage of biotechnology investment which has been dominated by small independent firms, smaller markets were anticipated whereas chemical firms will be attracted to invest in substitutes as larger markets are anticipated. This transition, which appears to be in progress, is consistent with the results of this paper. However, if this is the proper interpretation, then both under investment and production of substitutes as well as complements can be anticipated.

This paper represents the beginnings of a general research agenda regarding the role of intermarket control economies in the modern theory of industrial organization. This literature (see Tirole, [1988] for a review) views industrial organization as a consequence of the economic/technological environment with contestibility a result of the economic/policy environment and investment in barriers to entry. To date, these considerations have focused on multiple firm possibilities in single markets or multiproduct cost considerations with given output prices. This paper examines a case of multiple but related output markets. Specifically, the paper examines the simple case where, because of patents and limited alternatives, contestibility in a given chemical market occurs only through the decision to develop a given biotechnology product that is related in demand. A more general approach would investigate the choice of product characteristics (complementarity/ substitutability) to develop among a wide range of alternatives (e.g., given the designer aspects of biotechnology) subject to imitation limitations under patent law. Marginally relaxing imitation limitations would tend to increase competition with existing products but reduce incentives for research and development of new products. The net effect on contestibility is thus open to question.

Another issue is the possibility of acquiring a patent for the purpose of restricting competition rather than for producing an additional product. Gilbert and Newbery [1982] have demonstrated that it can pay a monopolist to buy a patent and never use it simply to maintain a monopoly. However, their case relates only to a new way to produce an existing product. In the intermarket economies case of this paper where the issue of scope arises, the chemical monopolist may benefit by buying the patent for a biotechnology product and not producing in order to maintain a chemical monopoly. This problem reduces to the Gilbert-Newbery case only for perfect substitutes.

FOOTNOTES

[1]David Jackson, Director of Research for Pharmaceuticals/Biotechnology, Dupont.

[2]To translate from conditions on flexibilities into price elasticities, consider direct demands $X = \tilde{X}(u,v)$, $Y = \tilde{Y}(u,v)$ which yields $\tilde{X}_u\, du + \tilde{X}_v\, dv - dX = 0$ and $\tilde{Y}_u\, du + \tilde{X}_v\, dv - dY = 0$. Comparative static analysis yields $du/dX = u_x = \tilde{Y}_v/D^*$, $dv/dX = v_x = -\tilde{Y}_u/D^*$, $du/dY = u_y = -\tilde{X}_v/D^*$, and $dv/dY = v_y = \tilde{X}_u/D^*$ where $D^* = \tilde{X}_u \tilde{Y}_v - \tilde{X}_v \tilde{Y}_u > 0$ follows from $u_x v_y - u_y v_x > 0$. Thus,

$$\frac{dX}{d\nu} > (<)\ 0 \text{ if } \varepsilon^v_y - \varepsilon^v_x = \frac{\varepsilon^x_u + \varepsilon^y_u}{\varepsilon^x_u \varepsilon^y_v - \varepsilon^x_v \varepsilon^y_u} >> (<<)\ 0$$

$$\frac{dY}{d\nu} > (<)\ 0 \text{ if } \varepsilon^u_x - \varepsilon^u_y = \frac{\varepsilon^y_v + \varepsilon^x_v}{\varepsilon^x_u \varepsilon^y_v - \varepsilon^x_v \varepsilon^y_u} >> (<<)\ 0.$$

One can verify that the right hand side of the condition for $dX/d\nu$ tends to become highly negative as the numerator gets large negatively (ε^x_u gets large negatively relative to ε^y_u) and as the denominator gets small (ε^y_v gets small and cross elasticities get large). The latter occurs as the product of cross elasticities approaches the limiting product of own elasticities. Note that $\varepsilon^x_u \varepsilon^y_v - \varepsilon^X_V \varepsilon^Y_u > 0$ follows from $u_x v_y - u_y v_x > 0$.

[3]Again, this intuition can be made formal as in footnote 1.

[4]From footnote 1, these statements translate directly into equivalent statements about price elasticities of the opposite good.

[5]That is, from (4) one finds the reaction functions $X = X(Y)$ and $Y = Y(X)$ for each industry by total differentiation, $\pi_{xx}\, dX + \pi_{xy}\, dY = 0$, $\pi_{yy}\, dX + \pi_{yx}\, dY = 0$. These reaction functions are characterized by $X_y = \pi_{xy}/\pi_{xx}$ and $Y_x = \pi_{yx}/\pi_{yy}$. Thus, for a small change dX from equilibrium, the nth round adjustment is $(X_y)^n (Y_x)^n\, dX = (\pi_{xy}\pi_{yx}/\pi_{xx}\pi_{yy})^n\, dX$. This adjustment process converges if and only if $|\pi_{xy}\, \pi_{yx}| < |\pi_{xx}\, \pi_{yy}|$. Note that a similar stability condition was employed by Bulow, et al.

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APPENDIX A: SECOND ORDER CONDITIONS

To examine second order conditions associated with (4), define

$$\pi_{xx} \equiv \partial\pi_x/\partial X = u_{xx}\, X\mu + u_x\, \mu + \nu_{xx}\, Y\nu + u_x - h_{xx}$$

$$\pi_{yy} \equiv \partial\pi_y/\partial Y = u_{yy}\, X\nu + v_{yy}\, Y\mu + v_y\, \mu + v_y - g_{yy}$$

$$\pi_{xy} \equiv \partial\pi_x/\partial Y = u_{xy}\, X\mu + v_{xy}\, Y\nu + v_x\, \nu + u_y$$

$$\pi_{yx} \equiv \partial\pi_y/\partial X = u_{xy}\, X_\nu + u_y\, \nu + v_{xy}\, Y\mu + v_x,$$

so that second order conditions are given by $\pi_{xx} < 0$, $\pi_{yy} < 0$, and, in the cases of the joint industry and the social optimum where $\pi_{xy} \equiv \pi_{yx}$, $D \equiv \pi_{xx}\pi_{yy} - \pi_{xy}\,\pi_{yx} > 0$. However, the latter condition must also hold in case of separate industries under the assumption of stability.[5] These second order/stability conditions are assumed to hold for any convex combination of industry structures (any values of μ and ν in the unit interval). Thus, behavior in the alternative structures can be compared by comparative static analyses of (4) with respect to μ and ν. Several useful results follow directly from the resulting negative definiteness of

$$\Pi = \begin{bmatrix} \pi_{xx} \pi_{xy} \\ \pi_{yx} \pi_{yy} \end{bmatrix}$$

including

$$[X - Y]\ \Pi\ [X - Y]' = X(\pi_{xx}\, X - \pi_{yx}\, Y) + Y(\pi_{yy}\, Y - \pi_{xy}\, X) < 0$$

$$[v_y\, Y \quad -u_x\, X] \quad \pi[v_y\, Y \quad -u_x\, X]'$$
$$= u_x\, X(\pi_{yy}\, u_x\, X - \pi_{xy}\, v_y\, Y) - v_y\, Y(\pi_{yx}\, u_x\, X - \pi_{xx}\, v_y\, Y) < 0$$

$$[(v_x\, X + v_y\, Y) \qquad -(u_x\, X + u_y\, Y)]\ \Pi\ [v_x\, X + v_y Y) \qquad -(u_x\, X + u_y\, Y)]'$$
$$= (u_x\, X + u_y\, Y)\ [\pi_{yy}(u_x\, X + u_y\, Y) - \pi_{xy}(v_x\, X + v_y\, Y)]$$
$$- (v_x\, X + v_y\, Y)[\pi_{yx}(u_x\, X + u_y\, Y) - \pi_{xx}(v_x\, X + v_y\, Y)] < 0.$$

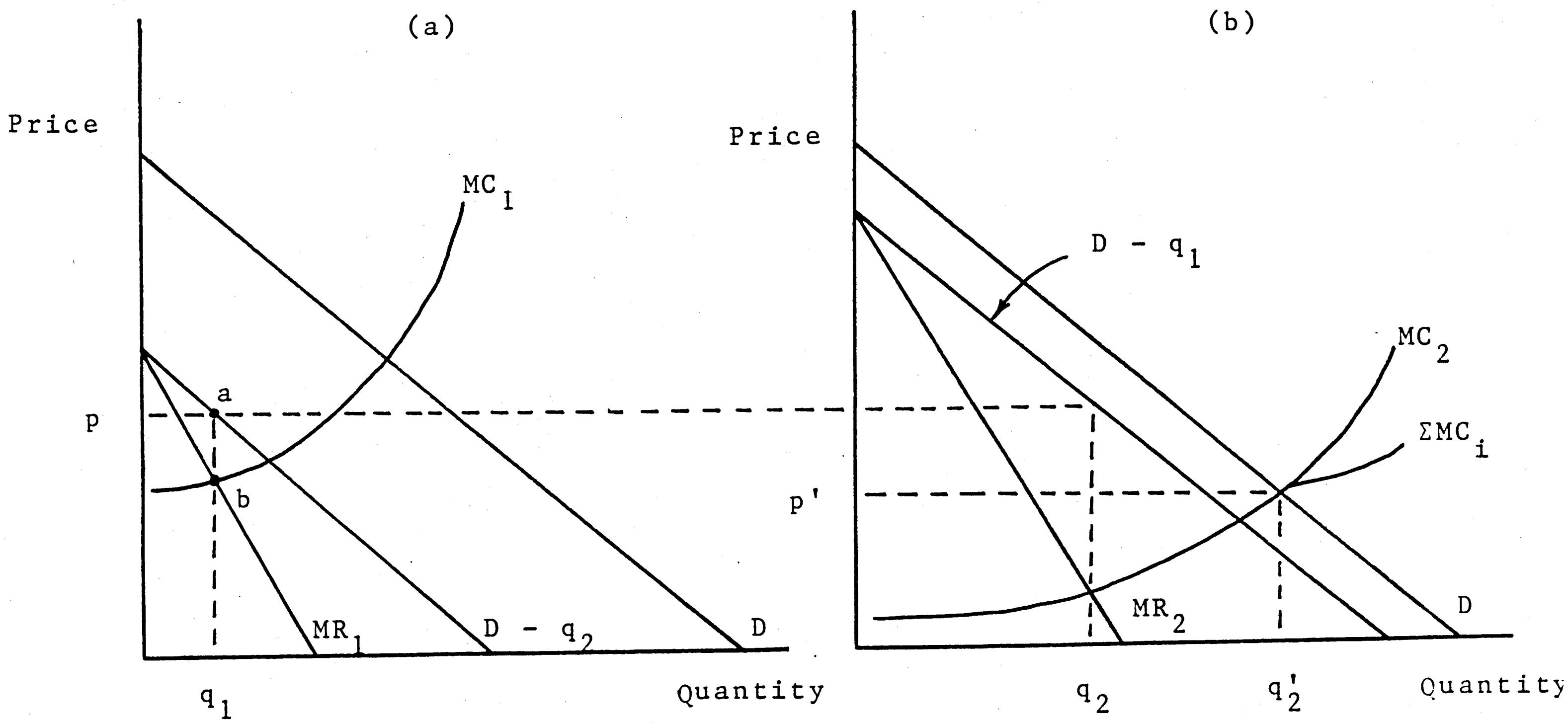

Figure 1. Co-monopoly Production of Perfect Substitutes