INTELLECTUAL PROPERTY RIGHTS
AND THE WELFARE EFFECTS OF AGRICULTURAL R&D

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March 1997

Staff Paper # 286

Giancarlo Moschini and Harvey Lapan are Professors in the Department of Economics, Iowa State University, Ames, IA 50011. This is journal article J-17112 of the Iowa Agriculture and Home Economics Experiment Station, Project No. 3272. The support of the U.S. Department of Agriculture, through a National Research Initiative grant, is gratefully acknowledged.

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Abstract

This article reviews the nature of intellectual property rights in agriculture and outlines a modeling framework that accounts for relevant institutional features of agricultural R&D. The analysis emphasizes vertical market linkages in a model where agricultural innovations adopted by farmers are produced upstream by input suppliers. It is argued that the conventional assumption of competitive pricing in the rest of the economy cannot hold when new technologies are produced by private firms, because such innovations are typically protected by intellectual property rights (such as patents) which confer (limited) monopoly rights to the discoverer. The implications of intellectual property rights for the welfare evaluation of agricultural R&D are derived, and it is shown that conventional methods usually overestimate the welfare gains from agricultural innovations.

Key words: agricultural innovations, consumer surplus, input markets, patents, producer surplus.

Intellectual Property Rights and the Welfare Effects of Agricultural R&D

The profound changes that have affected the agricultural sector of developed countries in modern times are perhaps best illustrated by the evolution of production techniques. Mechanization, new chemical inputs such as herbicides, pesticides and fertilizers, genetic selection of crops and animals, new crop varieties, and countless other technical and organizational improvements have allowed a generalized increase in physical output while, at the same time, agriculture suffered a massive exodus of labor forces towards the non-farm sectors. Indeed, one of the stylized facts of developed countries post-war growth is that productivity in agriculture has grown faster than that of other sectors (Jorgenson and Gollop). This remarkable record naturally begs the question of what is at its root, and a view that commands considerable consensus is that agricultural productivity growth is due to (past) investments in scientific research and development (R&D).

Following the early work of Griliches (1958), a number of studies have analyzed economic issues related to the effects of agricultural research. We cannot begin to do justice to this impressive collection of contributions, but fortunately two recent texts can fill that need (Alston, Norton and Pardey; Huffman and Evenson, 1993). A central issue in this setting concerns the measurement of the size and distribution of the economic benefits from the technical progress that stems from agricultural R&D. A large majority of studies has relied on measuring changes in the economic surplus (consumer and producer surplus) evaluated in the agricultural product market. The basic idea is that improved production techniques allow farmers to supply a larger amount of output for any given price level, i.e., we have a productivity-induced supply shift. A prototype model is represented in figure 1, where $S_0(p)$ represents the pre-innovation supply curve, $S_1(p)$ represents the post-innovation supply curve, and $D(p)$ is the demand curve. For this closed-economy partial-equilibrium framework, area $ABCD$ is conventionally taken as measuring the increase in economic surplus, what is often called the "gross annual research benefit."

To be sure, a number of issues have been noted in the context of this measurement problem. First of all, although the analytical framework of virtually all previous empirical studies can be reduced to a version of the model in figure 1 (as illustrated in Alston, Norton, and Pardey), the specific assumptions have changed from study to study.[1] Second, the consumer surplus portion of the welfare metric strictly applies only if there are no income effects. Third, the welfare interpretation of the producer surplus portion of the measurement hinges on exactly what supply functions are represented by curves $S_i(p)$ (i=0,1) (i.e., what is being held constant in the analysis). This last point may be related to the validity of the partial equilibrium nature of the model, but there is widespread belief that the relevant research benefits can be measured in the output market using equilibrium demand and supply curves of sufficient generality.[2] In any case, it is understood that the validity of these welfare measures presupposes optimality conditions in the rest of the economy (i.e., competitive pricing conditions everywhere and no missing markets).

In this article we focus on this last point and we argue that, under circumstances that are becoming increasingly important for agricultural innovations in the United States, the competitive price conditions underlying the measurement in figure 1 cannot be invoked. Essentially, the traditional model discussed above pertains to innovations that are the result of public scientific research and that are physically provided either directly by the government or by competitive agents. As documented by Huffman and Evenson (1993), and by Alston, Norton and Pardey, much of the past research in agriculture has been of

[1] For example, some studies have calculated agricultural R&D benefits conditional on a given input bundle (e.g., Griliches, 1964), whereas others have allowed for the optimal input mix to adjust while holding fixed input and output prices (e.g., Huffman and Evenson, 1989; Chavas and Cox). Yet others have also allowed output price to adjust as in figure 1 (e.g., Zachariah, Fox, and Brinkman), but with input prices again held constant.

[2] See Alston, Norton and Pardey (1995, p. 232). This claim is based on the work of Just and Hueth and Just, Hueth and Schmitz although it is recognized that the "consumer" or "producer" surplus interpretation of welfare measures may be problematic in some cases. See also Thurman.

this nature. This has certainly been the case, for example, for many research activities carried out by the United States Department of Agriculture (USDA) and by land grant universities. Indeed, the atomistic structure of agricultural production explains why virtually none of the relevant R&D is carried out by farms directly engaged in production, and this structure has sometimes been cited as a reason for the need for publicly funded research in agriculture. When agricultural innovations are solely due to the research efforts of a benevolent public authority, then the simple model represented in figure 1 may be appropriate to value the social benefits of such research (subject to the other caveats mentioned earlier).

Whereas publicly sponsored research institutions have been and are actively involved in agricultural research, it is a fact that a sizable (and increasing) portion of agricultural R&D is performed by private firms that typically supply inputs to agriculture. The innovations produced by private firms are usually protected by Intellectual Property Rights (IPR), such as patents, which confer monopoly rights to the discoverer (with some limitations). Furthermore, in an environment of declining public support for state universities, patent protection is now being routinely sought for many innovations developed by land grant universities in an effort to increase revenue from non-traditional sources. Of course, protection of intellectual property has social benefits, and a patent system has long been recognized as useful in providing incentives to innovators given the public good nature of R&D output (knowledge). But what this means is that, as part of the socio-institutional setting of knowledge production, one needs to recognize that agents endowed with monopoly rights (as conferred by patents) will exploit them. Thus, insofar as agricultural innovations are protected by IPR, then the competitive price conditions underlying the measurement in figure 1 cannot be invoked. As shown in this paper, this observation can drastically change the analytic framework for evaluating the size and the distribution of the benefits from agricultural innovations.

The article is organized as follows. First, we briefly review the nature of IPR for agricultural innovations, and discuss the increasing importance of private R&D for U.S. agriculture. We then propose a formal model of new technology diffusion that captures the essential features of many agricultural innovations. The welfare measures appropriate for this model are derived, for both the instances of drastic and non-drastic innovations, and they are compared with the traditional measures that are relevant for publicly produced innovations. Finally, the results of a simulation exercise illustrate the quantitative effects of correctly accounting for IPR on the size and distribution of welfare gains.

Intellectual Property Rights and Agricultural R&D

The principle of protecting the products of human ingenuity so as to create incentives for inventiveness and progress has long been recognized in the legal system of most countries. In the United States this protection takes the form of patents, copyrights, trademarks and trade secrets (Besen and Raskind). The patent right is perhaps the most powerful means of protecting intellectual property, essentially endowing the patent holder with monopoly rights on the innovative product/process for a limited time period (usually 17 years). Not all of the inputs into agricultural production fall within the statutory domain of utility patents. In particular, because patents are not meant to apply to 'products of nature,' the output of agronomic and biological research was for a long time offered a different kind of intellectual property protection (Kjeldgaard and Marsh). The Plant Patent Act of 1930 provides protection for asexually reproduced plants.[3] Intellectual protection for sexually reproduced plants is offered by the Plant Variety Protection Act of 1970 in the form of 'protection certificates.' Although these certificates are not patents (they are issued by the USDA rather than the Patent and Trademark Office), the protection they offer is essentially the same as utility patents. This is especially true after the

[3] The exclusion of sexually reproduced plants from this protection was rooted in the assumption that sexually reproduced plants could not be propagated true-to-type. Plants patents differ from utility patents in a number of ways. In particular, they do not require the extensive detail description demanded of utility patents, and they are limited to a single claim (whereas a utility patent offers claims to multiple variations of the same invention).

1995 Supreme Court decisions restricting farmers' right to resell protected seeds (Fuglie et al.).

More recent developments aimed at protecting biotechnology innovations started with the 1980 Supreme Court decision in *Diamond vs Chakrabarty* (Office of Technology Assessment). The end result is that an array of genetically modified plants (both by traditional breeding methods as well as by molecular transformations) and other living organisms are now in the statutory domain of utility patents. Transgenic farm animals can be expected in the non-distant future (O'Connor), and transgenic plants have already been produced and patented, including the Agricetus patent pertaining to genetically engineered cotton, Monsanto's "roundup-ready" soybean, and, more recently, Bt corn resistant to the European corn borer. [4] In addition to the increased relevance of utility patents, one should stress that trade secrets law offers further protection of intellectual property that is relevant to plants. This is particularly important for hybrid varieties (virtually all corn, for example), where commercialized F_1 seeds ensure hybrid vigor only for the first generation of plants. In this case the valuable 'information' is in the parent lines which are typically not commercialized and which, as the case of *Pioneer vs Holden* demonstrated, can be effectively protected by trade secrets law (Kjeldgaard and Marsh).

From the foregoing, it is clear that agricultural innovations can be covered by intellectual property rights that give the innovator the ability to exclude others from making, using or selling the new product or process. Private firms that engage in agricultural R&D can therefore be expected to count on this protection when making investment decisions. But how important is private R&D in agriculture? Table 1 reports data on private and public agricultural R&D expenditures for the period 1960-1992. Whereas both sources of research are important, since 1980 the private sector has invested more in agricultural R&D that the public sector (which includes both USDA and land grant universities' expenditures). For

4 Here Bt stands for *Bacillus thuringiensis*, the bacteria that is the source of the genetic material that makes the plant resistant to the corn borer.

the last observation year (1992), private R&D was about 30 percent more than public R&D.[5] Looking at the composition of private agricultural R&D investments, it emerges that the most important area is that of agricultural chemicals. Innovations of this kind of products (herbicides, pesticides, and fertilizers) clearly fall within the boundary of utility patents. The same holds true for agricultural machinery (whose relative importance has declined over this observation period) and animal feed and health products. For plant breeding research, the changing landscape of IPR law discussed above applies. The other major area of private research is in post-harvest innovations (food processing and the like) where, again, one would expect standard patent law to apply.[6]

Whereas the evidence just discussed underscores the importance of private R&D in agriculture, it may actually underestimate its impact in terms of innovations affecting agricultural production for two reasons. First, publicly sponsored research tends to privilege more "basic" rather than "applied" research, as explained by Huffman and Evenson (1993, chapter 5).[7] Thus, the output of considerable publicly funded research is an input in more applied research, and thus conceivably contributes to private innovations protected by IPR. Second, insofar as public research is of the applied type, it can also be patented by public organizations, and thus it is not obvious that it ought to be treated differently than any other proprietary discovery in our context.[8] In conclusion, it seems clear that private agricultural R&D is

[5] Actually, as noted by Klotz, Fuglie and Pray, table 1 may underestimate the private sector's agricultural R&D because their data on livestock and agricultural biotechnology research was incomplete.

[6] Indeed, Huffman and Evenson (1993, p. 141) report that for the period 1830-1980 only 2.5 percent of post-harvest innovations were produced by public sector research.

[7] The distinction between "basic" and "applied" research dates back to Arrow.

[8] The USDA always had a policy of patenting innovations, although until 1980 it was required that they be licensed on a non-exclusive basis. This policy changed in 1980, and it is now possible for federally owned patents to be licensed on an exclusive basis. Since 1984 it is also possible to seek private patents for research partially funded by the Federal government. Furthermore, in an era of declining funding sources, land grant institutions are now aggressively pursuing the patenting of innovations from university research. At any rate, it is a fact that even for new crop varieties (traditionally an area of heavy public research) patents and certificates are mainly owned by private firms (Fuglie, Klotz and Gill).

fundamental to the introduction of innovations in agricultural production, and that private innovations are bound to be protected by intellectual property rights. In what follows we show that this observation can have fundamental implications for the measurement and interpretation of the economic benefits from agricultural research.

Agricultural Innovations and the Input Markets

In the model we develop, agricultural production is carried out by a large number of competitive farms that do not engage in any research activities. We consider explicitly the case of innovations for production agriculture but not post-harvest innovations. The relevant R&D is carried out by firms that supply inputs to the farm sector (seeds, chemicals, machinery, etc.). Thus, to realize the economic benefits of innovations, these firms need to transfer the new technology to the competitive agricultural sector. We assume that innovations take the form of new and improved versions of a given input (a pesticide with a more effective active ingredient, an herbicide with a broader spectrum of control, a fertilizer that is better absorbed by a given plant, a more productive seed variety, a more powerful tractor, etc.), and that the transfer of technology is achieved by selling the new and improved inputs to the competitive farm sector.

This set-up is akin to the models of technology diffusion through licensing that has been the object of considerable research. In such models, however, licensing typically entails the transfer of new technology between firms that are all engaged in final production in an oligopolistic setting (Gallini and Winters; Katz and Shapiro, 1985), such that the option not to license is still viable for the innovating firm. Or, when it is assumed that R&D is carried out by a research lab not engaged in production but licensing to downstream firms (Kamien and Tauman; Katz and Shapiro, 1986), the option of licensing only to a few firms (or only one firm) is still available, so that the strategic interaction between licensees plays an important role in the analysis. [9] For example, in the model of Kamien and Tauman, an innovator that can potentially license to a competitive industry would still optimally choose to license only one firm when the innovation is drastic. In our model, on the other hand, because of obvious features of the agricultural production process, we assume pure competition for the downstream adopting farms, and we assume that this structure is not affected by the introduction of innovations. Furthermore, we assume that the innovations are embodied in inputs, such that selling the improved input is the only way for the innovating firm to "license" its R&D output. In keeping with the foregoing discussion, it is assumed that the innovation is protected by IPR, and that the innovating firm is the only one that can supply the new input (and thus will price it accordingly).

Whereas the main contention of this paper is quite general and the qualitative results do not depend on a particular modeling choice, to characterize the problem it is necessary to be explicit about the specification of agricultural innovations. Thus, we assume that an agricultural commodity y can be produced either with an old technology according to $y = f(x_0, z)$ or with a new technology according to $y = g(x_1, z)$, where $f(.,.)$ and $g(.,.)$ are strictly concave production functions, x_0 denotes the pre-innovation input of interest, x_1 is the innovated input, and z represents all other inputs (for simplicity z is treated as a scalar). Furthermore, to make the analysis tractable, it is useful to relate the new production function to the old production function under the condition that the improved input is measured in the same physical units as the pre-innovation input. Three obvious ways of doing so are:

(1) $$g(x_1, z) \equiv f(\alpha x_1, z), \qquad \alpha > 1$$

[9] Questions that have been addressed in this context include the incentive to share innovations through licensing (Gallini and Winters; Katz and Shapiro, 1985), the effects that the possibility of licensing has on the incentives to innovate (Katz and Shapiro, 1985 and 1986), and the form of the optimal licensing contract (Kamien and Tauman; Katz and Shapiro, 1986; Gallini and Wright).

(2) $g(x_1,z) \equiv f(\alpha x_1, \gamma z)$, (α,γ) such that $f(\alpha x, \gamma z) > f(x,z)$

(3) $g(x_1,z) \equiv \alpha f(x_1,z)$, $\alpha > 1$

Thus, (1) corresponds to the case of an innovation augmenting only the own input. This could be a reasonable representation for, say, the case of a new version of an herbicide that has the same spectrum of control as an existing one, but with a more effective active ingredient. Alternatively, (2) assumes that innovation in the x-input leads to a general factor augmentation. This could be a reasonable representation for, say, an improved herbicide that possesses a broader spectrum of control than an existing one, such that it can substitute for other inputs. Finally, in (3) the innovation in the x-input shifts the whole production function (a Hicks-neutral innovation). This could be a reasonable representation for, say, a more productive seed variety. The simplest way of illustrating our contention that IPR matter for the purpose of evaluating R&D is by means of the first representation (although we stress again that our conclusions are not predicated upon a specific representation of technological innovation). Thus, in what follows we assume the innovation is own-input augmenting, as in equation (1).[10]

In the specification chosen, α represents the efficiency of the improved input, so that αx_1 denotes the amount of the improved input in the "efficiency units" of the old x-input. Once new and old inputs are measured in the same efficiency units, the specification chosen indicates perfect substitutability between the old and new input. In what follows we exploit this feature to simplify the analysis. Specifically, let $\hat{x}$ represent the input of interest measured in efficiency units. Thus, for the pre-innovation input we simply have $\hat{x}_0 \equiv x_0$, whereas for the innovated input we have $\hat{x}_1 \equiv \alpha x_1$. Correspondingly, let $\hat{w}$ denote the price of the x-input measured in efficiency units, such that we have

[10] Note that (1) is a special case of (2). For a homogeneous production function (of any degree) (3) is also a special case of (2). When the production function is Cobb-Douglas, the three representations just discussed are indistinguishable.

$\hat{w}_0 \equiv w_0$ and $\hat{w}_1 \equiv w_1/\alpha$. If p denotes the price of the agricultural output and r the price of other inputs, the profit function dual to $f(.,.)$ is:

$$\pi(p,\hat{w},r) \equiv \max_{\hat{x},z}\{pf(\hat{x},z) - \hat{w}\hat{x} - rz\} \tag{4}$$

Irrespective of whether the new or old technology is being used, output supply y^* and input demand (in efficiency units) $\hat{x}^*$ can be retrieved via Hotelling's lemma:

$$y^* = \pi_p(p,\hat{w},r) \tag{5}$$

$$\hat{x}^* = -\pi_{\hat{w}}(p,\hat{w},r) \tag{6}$$

where the subscripts to π denote partial derivatives. Thus, for example, if farmers use the old technology with w_0 being the price of x_0, farmers' profits are given by $\pi(p,w_0,r)$, with output supply $y^* = \pi_p(p,w_0,r)$ and input demand $x_0^* = -\pi_{\hat{w}}(p,w_0,r)$. On the other hand, if farmers use the new technology with w_1 being the price of x_1, then farmers' profits are $\pi(p,w_1/\alpha,r)$, with output supply $y^* = \pi_p(p,w_1/\alpha,r)$ and input demand $x_1^* = -(1/\alpha)\pi_{\hat{w}}(p,w_1/\alpha,r)$.

From this specification it is clear that the farmer will adopt the new innovation if $\hat{w}_1 \le \hat{w}_0$, that is if $(w_1/\alpha) \le w_0$.[11] Thus, at this point the relevant question concerns the level of prices w_0 and w_1 that are likely to emerge in equilibrium. To say something about that, further assumptions are needed. First, to close the model, let *D(p)* denote the (downward sloping) demand for the agricultural output. Thus, for given input prices $\hat{w}$ and r, the agricultural output equilibrium price $p^* \equiv p(\hat{w},r)$ will solve:

$$D(p^*) = \pi_p(p^*,\hat{w},r) \tag{7}$$

[11] Strictly, if $w_1 = w_0\alpha$ the farmer is indifferent as to which input is used, but following standard convention we assume that in such a case adoption of the improved input occurs.

Second, assume that both x_0 and x_1 are produced with constant marginal cost c, and that the price r of other inputs is exogenously given. Thus, the profit of the firm producing the innovated input are given by $(w_1 - c)x_1 = (\hat{w}_1 - c/\alpha)\hat{x}_1$. Because the new input is protected by IPR, the innovating firm will try to charge the profit-maximizing monopolistic price (expressed in efficiency units) $\hat{w}_1^m$. More precisely, let:

$$\text{(8)} \qquad \chi(\hat{w}) \equiv -\pi_{\hat{w}}(p(\hat{w},r),\hat{w},r)$$

represent the derived demand (in efficiency units) for the innovated input, that is, the input demand accounting for equilibrium in the agricultural output market. Then the monopolistic price $\hat{w}_1^m$ is:

$$\text{(9)} \qquad \hat{w}_1^m \equiv \arg\max_{\hat{w}_1} \left\{ \left(\hat{w}_1 - \frac{c}{\alpha} \right) \chi(\hat{w}_1) \right\}$$

The monopolistic price in (9), however, is not feasible if the adoption constraint $\hat{w}_1 \le \hat{w}_0$ is binding. Following Arrow, we say that the innovation is "drastic" if the firm can charge $\hat{w}_1^m$, whereas it is "non-drastic" if the innovating firm is constrained to charge the upper bound $\hat{w}_0 < \hat{w}_1^m$.[12] In addition, in considering the innovator's pricing decision we must account for the behavior of other firms (the producers of x_0). Thus, the two interrelated factors that need to be considered in describing how the price for the new innovation is determined are: (i) the previously existing market structure, and (ii) whether the innovation is drastic (leading to unconstrained monopoly price of the innovated input) or non-drastic (so that the monopolist's pricing decision is constrained by the threat of competition). As will be shown below, the impact of the innovation on welfare, and the measurement of the welfare change in the agricultural markets, depend on whether the innovation is drastic or non-drastic, and on the market

[12] Clearly, because the upper limit of the constraint (αw_0) is monotonically increasing in α, an innovation is more likely to be drastic the larger is the efficiency parameter α.

structure that prevailed prior to the innovation.[13] Thus, in what follows we examine all these cases separately.

Measuring Welfare Changes for a Non-Drastic Innovation

Consider first the case of a non-drastic innovation, in which the innovating firm cannot charge its unconstrained monopoly price $\hat{w}_1^m$. The impact of the innovation on the input price involves two separate cases: (i) the producers of the original input behave as perfect competitors (e.g., the production of x_0 involves a publicly available process); and (ii) x_0 was sold at a price above marginal cost (this latter case could occur when the new patented innovation supersedes a previously available patented innovation that was also sold at a non-competitive price). In the latter instance, the introduction of the innovated input x_1 establishes a duopoly structure in the input market. As is well known, the equilibrium outcome in such a case depends crucially on the kind of strategic game played by the duopolists (cfr. Mas-Colell, Whinston, and Green, chapter 12). In this paper we assume that price is the strategic variable of input suppliers, i.e., Bertrand competition occurs. This assumption is consistent with our previous one that incumbent and innovating firms both have identical and constant marginal cost c, and it is arguably appealing for the problem at hand (the diffusion of new technology that has already been produced). In some sense, the Bertrand competition assumption is also the conservative one. Assuming Cournot behavior would yield lower social benefits from innovations, implying that the overestimate of actual returns obtained by using the conventional method (illustrated later) would be even larger.

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[13] If the pre-innovation input x_0 is also patented and sold at a price exceeding marginal cost, the innovation supplants a previous one. This is what Schumpeter called the process of "creative destruction." In such a case, an effect of the innovation is to redistribute monopoly rents, as well as introducing a superior product.

Innovation with initial competitive input pricing

When the input of interest is initially competitively priced, then $w_0 = c$. Hence, the new input price is constrained to satisfy $\hat{w}_1 \le c$ (that is, $w_1 \le \alpha c$). As previously indicated, if α is not too large, this pricing constraint is likely to bind, so that we will have $w_1 = \alpha c$ (hence, the innovation is non-drastic). In this case, the efficiency price of the input will be unchanged by the innovation (i.e., $\hat{w}_1 = \hat{w}_0 = c$). Since the farmers' profits, and output, depend upon output price and the price $\hat{w}$ of the effective input, and not upon the measure of technology directly, the post-innovation and pre-innovation supply curves coincide and the farmers' profit (producer surplus) is unchanged by the innovation. What is happening is that the increase in efficiency due to the innovation, *ceteris paribus,* shifts the supply curve rightward but the concomitant increase in factor price shifts the supply curve backward so that overall there is no change. As illustrated in figure 2, the relevant post-innovation supply curve in this case is $S_1(p) \equiv y(p, w_1/\alpha, r)$, were $w_1/\alpha = w_0$. Because the *effective* price of inputs is unchanged, producers and consumers of agricultural products are unaffected by the innovation.

The actual (gross) social gains, for this case, are given by the profits earned by the monopolist because originally (under the competitive constant cost assumption) input producers earned no surplus, and because there is no change in surplus for producers or consumers of agricultural products. Hence, the welfare gain of a non-drastic innovation when the pre-innovation input is competitively priced is:

$$(10) \qquad \Delta SW^{N,C} = \left(c - \frac{c}{\alpha}\right)\hat{x}_1^* > 0$$

where $\hat{x}_1^* = -\pi_{\hat{w}}(p(c,r),c,r)$ is the demand in efficiency units for the new x-input (the level of which is not changed by the innovation, i.e., $\hat{x}_1^* = \hat{x}_0^*$). As long as the innovation is non-drastic, the gains in (10) increase with the innovation (but at a decreasing rate, *i.e.,* $\Delta SW^{N,C}$ is concave in α).

In measuring the social gains it is interesting to note that, under the assumption of constant marginal costs in the input market, our factor-augmenting innovation is isomorphic to a decrease in the x-input unit cost, i.e., we have a supply shift in the input market. Now, in general it is not possible to compute the total welfare effects of a supply shift in the input market by measuring the change of Marshallian surplus in the market for the output which employs that input.[14] In the special case of constant marginal costs considered here, however, the welfare gains from such an input supply shift could in fact be measured in the output market if inputs were competitively priced (because there is no surplus that accrues to input producers). Thus, our inability to measure the total welfare effect of the innovation as a change in surplus in the agricultural output market here is solely due to the monopoly pricing in the input market which is made possible by the existence of IPR.

Innovation with pre-existing monopoly in the input market

If originally there is monopoly power in the input market, then the new innovation (even if it is non-drastic) will affect the input price (in efficiency units) and hence will lead to changes in surplus in the agricultural market. If we let $w_0 > c$ denote the monopoly price prior to the innovation, then under Bertrand competition the innovator's pricing decision is still constrained by $w_1 \leq \alpha c$ (that is, $\hat{w}_1 \leq c$), because the original monopolist will be willing to reduce price to c before giving up the entire market to the innovating firm. For a non-drastic innovation we will then have $\hat{w}_1 = c$. Thus, the innovation leads to a decrease in efficiency price for the input, an increase in the use of the input when measured in efficiency units ($\hat{x}_1^* > \hat{x}_0^*$), and an increase in surplus in the agricultural market. It is interesting to note

[14] The change in surplus measured in the output market would be equivalent to the change in "consumer surplus" associated with the derived demand for the input whose supply has shifted (Just and Hueth). But this is only a partial measure of the overall welfare effect if the input supply is upward sloping, because in such a case the change in rents accruing to the producers of this input must also be taken into account. This point is explicitly illustrated in the next section.

that even if the new "innovation" is less efficient than the old one ($\alpha < 1$), it may still lead to a price reduction (in efficiency units), and thus increase measured surplus in the agricultural market, because the initial monopolist must lower price to maintain his market. Essentially, the new innovation, while dominated, reduces the market power of the monopolist and will have some social value, though (again) this will not be properly measured in the final product market.

To illustrate more precisely what the surplus in the agricultural market measures, assume the indirect utility function of consumers is quasilinear (such that Marshallian surplus is an exact measure of welfare), that is $V(p,I) = I + v(p)$, where as before p is the price of agricultural products and I is consumers' income. By Roy's identity, the demand for agricultural output is then $D(p) \equiv -v'(p)$. Total surplus (social welfare) before and after the innovation are given by:

$$(11) \qquad SW_0 = \{I + v(p_0)\} + \pi(p_0, w_0, r) + (w_0 - c)\hat{x}_0^*$$

$$(12) \qquad SW_1 = \{I + v(p_1)\} + \pi(p_1, c, r) + \left(c - \frac{c}{\alpha}\right)\hat{x}_1^*$$

where $p_0 \equiv p(w_0, r)$, $p_1 \equiv p(c, r)$ (and thus $p_1 < p_0$ because $w_0 > c$), $\hat{x}_1^* = -\pi_{\hat{w}}(p_1, c, r)$, and $\hat{x}_0^* = -\pi_{\hat{w}}(p_0, w_0, r)$. In equations (11) and (12) the first term within braces on the RHS is the consumer surplus, the second is agricultural producer surplus, and the last is the input supplier's monopoly profit. Note that the first two terms do not depend directly on the innovation, but only on efficiency prices. Thus, the change in social welfare when a non-drastic innovation supersedes an existing monopoly, defined as $\Delta SW^{N,M} \equiv SW_1 - SW_0$, can be expressed as $\Delta SW^{N,M} = \Delta MS + \Delta\Pi^M$, where ΔMS denotes changes in Marshallian Surplus in the agricultural market and $\Delta\Pi^M$ denotes changes in monopoly profit in the input market. More specifically:

$$(13) \qquad \Delta MS = \{v(p_1) - v(p_0)\} + \{\pi(p_1, c, r) - \pi(p_0, w_0, r)\}$$

where the first set of braces on the RHS contains changes in consumer surplus and the second set of braces contains changes in farmers' profit (producer surplus). This change in surplus in the agricultural market can be measured, in the conventional way, by the change in area between the supply curve (which shifts due to the innovation and the input price change) and the demand curve. Thus, this change is given by area *ABEF* in figure 2 because the relevant post-innovation supply curve in this case is $S_1(p) \equiv y(p, w_1/\alpha, r)$, were $w_1/\alpha < w_0$ (but note that we are still dealing with a non-drastic innovation, and that the decline in efficiency input price here is due to the increased competition for the pre-existing monopoly). As for the distribution of Marshallian surplus, whereas consumer surplus increases due to the innovation (because $p_1 < p_0$), producer surplus need not increase if the demand for agricultural output is inelastic.[15]

The change in monopoly profits associated with the innovation is:

$$\text{(14)} \qquad \Delta\Pi^M = \left(c - \frac{c}{\alpha}\right)\hat{x}_1^* - (w_0 - c)\hat{x}_0^*$$

This change in monopoly profits in the input market cannot be measured in the output market. Note that for $\alpha \cong 1$ (a small innovation) monopoly profits must fall due to the innovation because of the increased competition in the input market, and thus in such a case the change in surplus in the final goods market (even when correctly measured as area *ABEF* in figure 2) would overstate the true value of the innovation. Indeed, the innovation embodied in x_1 could have social value even if $\alpha < 1$ (which means that, strictly, it is not a technological improvement) because it would alleviate the monopoly distortion. Although in such a case the "innovation" in x_1 would not be adopted, its development would lead to an increase in overall surplus, which will be *overmeasured* in the final goods market since this measurement

[15] Indeed, the interested reader can verify that, in the special case of a homogeneous agricultural production function (of degree < 1), agricultural producers will gain from the innovation if, and only if, final demand is elastic.

does not reflect the decline in monopoly rents.

The total welfare change due to a non-drastic innovation is perhaps best illustrated in the input market, as in figure 3, where $\chi(\hat{w})$ is the derived demand for the x-input defined earlier (the other curve in figure 3 is the innovator-monopolist's marginal revenue curve associated with this derived demand). Now, changes in the Marshallian surplus in the agricultural market can be represented as:

$$\begin{aligned} dMS &= \left[v'(p) + \pi_p(p,\hat{w},r)\right]dp + \pi_{\hat{w}}(p,\hat{w},r)d\hat{w} \\ &= -\chi(\hat{w})d\hat{w} \end{aligned} \tag{15}$$

where the second equality follows if market equilibrium in the agricultural market holds, such that $p = p(\hat{w},r)$ [recall that $-v'(p)$ is demand and $\pi_p(p,\hat{w},r)$ is supply]. Hence, the change in Marshallian surplus in the agricultural market can be expressed as:

$$\Delta MS = \int_c^{\hat{w}_0} \chi(\hat{w})d\hat{w} \tag{16}$$

In other words, the change in Marshallian surplus in the agricultural market can be measured as the area next to the derived demand (in efficiency units) for the input in question. Hence, area *ABEF* in figure 2 is equal to area $(a+b+d)$ in figure 3. But clearly this does not represent the entire welfare change, as the variation in monopoly profits needs to be accounted for. In terms of figure 3, the change in monopoly profits is given by area $(e+f+g)$ minus area $(a+b)$.[16]

Figure 3 also makes it clear that a non-drastic innovation of size α leads to larger social gains when a pre-existing monopoly initially prevails than when pure competition initially prevails (that is, $\Delta SW^{N,C} \leq \Delta SW^{N,M}$), the larger gains being essentially due to the increase in x-input use. In particular,

[16] The situation of a non-drastic innovation when competition initially prevails, discussed earlier, can be illustrated in figure 3 as well. In such a case, both pre- and post-innovation input levels equal $\hat{x}_1^*$, and the welfare gains is given by area $(e+f+g)$.

when the innovation replaces an existing monopoly, the additional welfare gain is equal to area d.

Measuring Welfare Changes for a Drastic Innovation

The other possible case is one in which the innovator's optimal price is unconstrained by the potential competition, that is $w_1^m < c\alpha$ (equivalently, $\hat{w}_1^m < c$). In this instance, the original market structure does not affect the price charged for the innovated input. Clearly, here there is an impact in the agricultural market because of the decline in price (in efficiency units) of the input. Analytically, the decline in efficiency price of the x-input leads to higher output and lower price in the agricultural market. Whether farmers gain or lose remains problematic, depending (largely) upon the elasticity of demand for the final product. Again, however, the total welfare effect cannot be measured in the output market alone because the changes in rents accruing to input suppliers are not represented in that market.

When competition in the input market prevails prior to the innovation, the welfare gain from a drastic innovation is given by:

$$(17) \qquad \Delta SW^{D,C} = \int_{\hat{w}_1^m}^{c} \chi(\hat{w}) d\hat{w} + \left(\hat{w}_1^m - \frac{c}{\alpha} \right) \hat{x}_1^*$$

where $\hat{w}_1^m < c$. The first term in the RHS of represents the change of Marshallian surplus in the agricultural market. This change is due to the decline in the price (in efficiency units) of the innovated input, and can be measured in the final output market as area $ABEF$ in figure 2. The total welfare effects of the innovation, however, must account also for the input suppliers' profit, and are best illustrated in the innovated input market, as in figure 4. Here, area (e+f+g+h) represents the change in the final output's Marshallian surplus (and thus it is equivalent to area $ABEF$ in figure 2), whereas the monopolists' profit is given by area (i+j+k+m+n).

When the innovating firm replaces an existing monopoly, the welfare gain from a drastic innovation is given by:

$$(18) \qquad \Delta SW^{D,M} = \int_{\hat{w}_1^m}^{\hat{w}_0} \chi(\hat{w})d\hat{w} + \left(\hat{w}_1^m - \frac{c}{\alpha}\right)\hat{x}_1^* - (\hat{w}_0 - c)\hat{x}_0^*$$

Again, the first term in the RHS of (18) represents the change of Marshallian surplus in the agricultural market. This change can be measured as area *ABEF* in figure 2 or as area $(a+b+d+e+f+g+h)$ in figure 4. The total welfare effects of the innovation, however, must account also for the change in the input suppliers' profit, which are given by area $(i+j+k+m+n)$ minus area $(a+b)$ in figure 4 (this difference could be negative). Note that, because:

$$(19) \qquad \int_{c}^{\hat{w}_0} \chi(\hat{w})d\hat{w} \geq (\hat{w}_0 - c)\hat{x}_0^*$$

then, as for the case of non-drastic innovation, the welfare gain from a drastic innovation will in general be larger if the innovating firm replaces an existing monopoly.

Comparison with Conventional Analysis: An Example

A common feature of virtually all previous empirical analyses is that they start with a measure of the shift in productivity brought about by technological innovations, estimated either by including R&D and related expenditures directly in an aggregate production function or in an agricultural supply function (see the studies reviewed by Alston, Norton, and Pardey). Neglecting for the moment the numerous estimation problems that such an endeavor necessarily entails, it would seem that the shift in the agricultural supply function due to innovations can be correctly identified regardless of the industry structure of the innovating industry. For example, for the model that we have analyzed, computation of multifactor productivity measures before and after the innovation would identify the supply shift from S_0 to S_1 of figure 1. Similarly, under certain identification conditions, estimation of an agricultural supply response with R&D variables on the right-hand-side could again correctly identify such productivity shift.[17] But, as explained at length earlier, what the conventional framework fails to do is to account for the fact that the introduction of agricultural innovations will typically result in changed equilibrium input prices (in addition to output price adjusting as in figure 1). Thus, the conventional approach is unlikely to provide a solid framework to evaluate the benefits from private research that is covered by IPR.

Having shown that the conventional method of evaluating the benefits from agricultural R&D is not appropriate for this model, one may ask by how much conventional estimates of R&D benefits differ from the correct one. Clearly, it is not possible to provide a single answer to this question. Although it is evident that the competitive model is not appropriate, which particular 'noncompetitive' model is adequate will depend on the specific type of innovation, as well as on the existing market structure prior to the innovation. Thus, future research may adapt the conceptual model discussed here to specific agricultural innovations, accounting for their particular technological features and institutional setting. However, to gain some insights into the parameters that are likely to affect the differences in welfare evaluation that may arise between the conventional framework and our framework, we consider an explicit parameterization of the theoretical model analyzed so far.

For this parametric model, suppose that the farmers' technology displays Constant Elasticity of Substitution (CES) between the innovated x-input and other inputs, and that there are decreasing returns to scale (supply is upward sloping). In other words, the profit function of the agricultural industry is:

$$\pi(p,\hat{w},r) = Ap^{1+\eta}\left[\beta\hat{w}^{1-\sigma} + r^{1-\sigma}\right]^{-\frac{\eta}{1-\sigma}} \tag{20}$$

where $A > 0$ is a scaling parameter, $\eta > 0$ is the (constant) farm supply elasticity, and $\sigma > 0$ is the (constant) elasticity of substitution between the two farm inputs. The parameter $\beta > 0$ determines

[17] As we have shown, the innovated input price will usually change as a result of innovations. Thus, to estimate the separate response of supply to R&D conditional on all input prices one needs additional sources of exogenous movements in the input prices so that the innovated input price series and the sequence of R&D expenditures are not perfectly correlated.

the x-input share of total costs (clearly, this share depends on input prices). Hence, for a given β the x-input demand is more elastic the higher σ. Agricultural output supply and input demand are easily derived from (20) via Hotelling's lemma. To close the model we specify a constant elasticity final demand, viz:

$$(21) \qquad D(p) = Bp^{-\varepsilon}$$

where $B > 0$ is a scaling parameter and $\varepsilon > 0$ is the (constant) elasticity of demand (expressed as a positive number). The equilibrium output price therefore is:

$$(22) \qquad p(\hat{w}, r) = \left(\frac{B}{A(1+\eta)}\right)^{\frac{1}{\eta+\varepsilon}} \left[\beta\hat{w}^{1-\sigma} + r^{1-\sigma}\right]^{\frac{\eta}{(\eta+\varepsilon)(1-\sigma)}}$$

The monopolist's derived demand for the improved x-input expressed in efficiency units is

$$(23) \qquad \chi(\hat{w}) = \beta\eta(1-\eta)^{-\frac{1+\eta}{\eta+\varepsilon}} A^{\frac{\varepsilon-1}{\eta+\varepsilon}} B^{\frac{1+\eta}{\eta+\varepsilon}} \hat{w}^{-\sigma} \left[\beta\hat{w}^{1-\sigma} + r^{1-\sigma}\right]^{\frac{\sigma(\eta+\varepsilon)-\varepsilon(1+\eta)}{(1-\sigma)(\eta+\varepsilon)}}$$

The monopolist sets $\hat{w}_1^*$ to maximizes profits, subject to the competitive price limit. This results in the following price for the improved x-input (in efficiency units):

$$(24) \qquad \hat{w}_1^* = \begin{cases} \dfrac{\theta(\hat{w}_1^*)}{1+\theta(\hat{w}_1^*)}\left(\dfrac{c}{\alpha}\right) & \text{if } \theta(\hat{w}_1^*) < -1 \quad \text{and} \quad \hat{w}_1^* < c \\ c & \text{otherwise} \end{cases}$$

where $\theta(\hat{w})$ is the own-price elasticity of the derived input demand in equation (23), that is:

$$(25) \qquad \theta(\hat{w}) = -\sigma + \left(\sigma - \frac{\varepsilon(1+\eta)}{(\eta+\varepsilon)}\right)\beta\hat{w}^{1-\sigma}\left[\beta\hat{w}^{1-\sigma} + r^{1-\sigma}\right]^{-1}$$

Hence, for given parameter values we can compute the equilibrium solution and the welfare measures before and after the innovation, both with the conventional method as well as with our approach described earlier (note that $\hat{w}_1^*$ cannot be computed analytically, but needs to be solved for numerically).

Table 2 reports some simulation results for alternative parameter values. In this table, we start by setting $c = r = 1$, and choose the arbitrary constants A and B such that the pre-innovation equilibrium has $p = 1$ and $y = 10{,}000$ (all of these normalizations are inconsequential for the relevant results of the simulations). Furthermore, we set $\beta = 0.1$ (this implies that the cost share of the x-input is approximately 0.09 in the initial competitive equilibrium). Given these assumptions, four parameters will determine the equilibrium solution and the welfare effects of the innovation: the final demand elasticity (ε), the agricultural supply elasticity (η), the x-input demand elasticity (controlled by the elasticity of substitution σ), and the magnitude of the innovation (α).

To understand the effects of these various parameters, in table 2 we first analyze a given innovation with $\alpha = 1.2$. Holding α constant, we consider two different values for each of the three remaining parameters $(\varepsilon, \eta,$ and $\sigma)$. For each combination of the parameter values that we consider, table 2 first reports the computed welfare changes for final consumers (ΔCS) and farmers (ΔPS) calculated with the conventional method (essentially area $ABCD$ in figure 1, except that with our functional forms the farm supply curves are borne in the origin). In the conventional framework, consumers always benefit from the innovation, whereas farmers benefit when final demand is elastic and lose when final demand is inelastic (a necessary implication of ourhomothetic production structure). The next three columns of table 2 report the welfare effects of the innovations on final consumers (ΔCS), farmers (ΔPS), and input suppliers ($\Delta\Pi^M$), computed according to the true model. It is clear that an important element of the alternative solutions is whether or not the upper limit c on the monopolistic price is binding, and for a given α this condition depends crucially on the elasticity of derived factor demand θ (which is controlled by σ). The competitive price limit here is binding for lower values of the elasticity of substitution ($\sigma = 0.5$ and $\sigma = 3$), whereas it is not binding for the larger value of this elasticity. As discussed earlier, when the competitive limit is binding, there are no welfare changes for farmers and final consumers, and all the gross benefits of research take the form of profits for the innovating input suppliers. On the other hand, when the competitive price limit is not binding, then consumers will benefit from the innovation. Whether farmers benefit or not again depends on the elasticity of final demand. The true welfare changes for consumers and farmers, however, are smaller than those indicated by the conventional approach. Thus, for example, when farmers gain from the innovation they gain less than that indicated by the conventional approach, but when they are hurt by the innovation they also lose less than that indicated by the conventional method.

To look at the overall social welfare effects of the innovation, one needs to add the profit of input suppliers, which are also reported in table 2. Clearly, all of these welfare measures are meaningful only when compared across the two methods, because their absolute value depends on the arbitrary normalization chosen. Thus, the last column of table 2 reports the ratio of total welfare gains measured in the conventional way to the actual total welfare gains according to the true model. Given that the initial condition is the competitive model, and that the conventional model (incorrectly, for our model) postulates competition for the post-innovation equilibrium as well, the conventional model must overestimate the benefits from innovation and thus this ratio should be greater than one in our setting.

From table 2 it is clear that, for the welfare comparisons that we are interested in, the crucial parameter is the elasticity of substitution (which here essentially determines the elasticity of the innovated input's derived demand). To understand this point it is useful to refer back to figure 3, which illustrates the welfare effects of a non-drastic innovation. For such a case, the conventional method would measure total welfare changes as area $(e+f+g+h)$ whereas by accounting for the monopoly position of the innovating firm we measure it as area $(e+f+g)$. Thus, the welfare overmeasurement by the conventional approach is given by area h. Clearly, as the derived demand becomes more elastic at the point $\chi(c)$, the welfare overmeasurement by the conventional method will increase (for any given size α of innovation).

From table 2 it is also clear that the elasticity of supply affects mostly the consumer surplus whereas the elasticity of final demand affects mostly the benefits to farmers (for the true model this only applies for drastic innovations). In any case, neither ε nor η seem to have much of an effect on the ratio of welfare measures as shown in the last column. Having illustrated this point, in table 3 we concentrate on the role of the elasticity of substitution σ and of the innovation parameter α. These two parameters are allowed to take three different values each, whereas the other two parameters are held at a value intermediate between those considered earlier, that is $\varepsilon = 1$ and $\eta = 1$. From the results reported in table 3, it appears that the crucial factor is again the elasticity of the derived demand for the improved input. For any given size α of the innovation, the overestimate of the conventional welfare measures relative to the true ones increase monotonically with the elasticity of derived demand for the x input. On the other hand, for any given σ, the ratio in the last column of table 3 increases monotonically with the size of the innovation α only as long as the innovation is non-drastic. It is noteworthy that even for a relatively small innovation size $(\alpha = 1.1)$, the overestimate of the conventional welfare measures relative to the true ones can be as much as 50 percent for the larger value of σ that we considered. Overall, for the range of parameters considered in tables 2 and 3, the conventional measure overestimates true welfare gains by as little as 3 percent and by as much as 61 percent.

Conclusion

There is little doubt that rapid increases in agricultural productivity have had significant consequences for farmers, as well as for all the upstream and downstream participants in the agricultural and food sector, including final consumers. There is a significant body of research that indicates these increases in productivity can be attributed to past research and development efforts. What is perhaps more debatable is how to appropriately measure the welfare benefits that are attributable to these innovations. Private innovators, endowed with the IPR protection provided by the legal system, will attempt to capture the benefits due to their innovation through monopoly pricing. As we have shown in this paper, this means that the conventional welfare measures that apply to publicly produced innovations will not be appropriate in these circumstances, and in general will tend to overstate the true benefits attributable to the innovations. Although this is an important conclusion, it should be noted that the most dramatic implication of correctly accounting for the monopolistic behavior entailed by IPR is not on the overall size of the benefits, but on the distribution of the welfare gains from innovations. In particular, for innovations introduced by suppliers of agricultural inputs, we find that what is conventionally measured as benefits to consumers and agricultural producers could in fact be totally captured by the innovating firms.

In this paper we have stressed that the correct evaluation of the benefits from R&D aimed at agriculture needs to account for the relevant institutional and industry structure responsible for the actual development of technological innovations. The recognition that agricultural innovations lead to non-competitive markets has other implications that may deserve further study. For example, the rapidity with which innovations will be adopted by potential users is likely to depend upon the market structure and pricing decisions of firms. Furthermore, the presence of monopolistic behavior due to past patented innovations is likely to affect the types of innovations that are pursued; the existing distortion means that the private and social values of various potential innovations may differ significantly. Finally, the innovators' incentive to disseminate an innovation to other potential users, such as agricultural producers in foreign countries, may conflict with private national benefits associated with the dissemination of such technology.

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Table 1. U.S. Annual Public and Private Agricultural R&D

Millions of current dollars

Year	Private R&D [a]						Total Public R&D [b]
	Plant Breeding	Agricultural Chemicals	Farm Machinery	Animal Health	Food & Kindred Products	Total Private R&D	
1960	6	27	75	6	92	206	216
1970	26	98	89	45	206	464	448
1980	97	395	363	111	488	1,453	1,214
1990	314	1,127	360	245	965	3,012	2,380
1992	400	1,279	394	306	1,038	3,416	2,605

Sources: (a) Klotz, Fuglie, and Pray, Table 8

(b) Alston and Pardey, Tables 2-A3

Table 2. Simulated Welfare Changes for CES Model, $\alpha = 1.2$

			Conventional Method		True Model			Ratio[(a)]
ε	η	σ (θ)	ΔCS	ΔPS	ΔCS	ΔPS	$\Delta \Pi^M$	
0.5	0.5	0.5 (-0.5)	79	-26	0	0	51	1.05
3	0.5	0.5 (-0.6)	23	30	0	0	51	1.05
0.5	3	0.5 (-0.5)	136	-17	0	0	114	1.05
3	3	0.5 (-0.6)	80	40	0	0	114	1.06
0.5	0.5	3 (-2.8)	98	-33	0	0	51	1.29
3	0.5	3 (-2.8)	28	37	0	0	51	1.30
0.5	3	3 (-2.8)	167	-21	0	0	114	1.29
3	3	3 (-2.9)	99	50	0	0	114	1.31
0.5	0.5	9 (-7.9)	163	-54	26	-9	54	1.54
3	0.5	9 (-8.0)	47	63	8	10	54	1.54
0.5	3	9 (-7.9)	279	-35	44	-5	120	1.54
3	3	9 (-8.1)	167	83	28	14	121	1.54

(a) ratio of welfare gains measured by the conventional method to total welfare gains of the true model.

Table 3. Simulated Welfare Changes for CES Model, $\varepsilon = 1$ and $\eta = 1$

		Conventional Method		True Model			Ratio[(a)]
σ (θ)	α	ΔCS	ΔPS	ΔCS	ΔPS	$\Delta\Pi^M$	
0.5 (-0.5)	1.1	42	0	0	0	41	1.03
3 (-2.8)	1.1	47	0	0	0	41	1.14
9 (-8.3)	1.1	62	0	0	0	41	1.50
0.5 (-0.5)	1.2	80	0	0	0	76	1.05
3 (-2.8)	1.2	98	0	0	0	76	1.29
9 (-8.0)	1.2	164	0	26	0	80	1.54
0.5 (-0.5)	1.4	142	0	0	0	130	1.09
3 (-2.8)	1.4	209	0	0	0	130	1.61
9 (-6.7)	1.4	507	0	153	0	215	1.38

(a) ratio of welfare gains measured by the conventional method to total welfare gains of the true model.

Figure 1. Gross Research Benefits: Conventional Measure

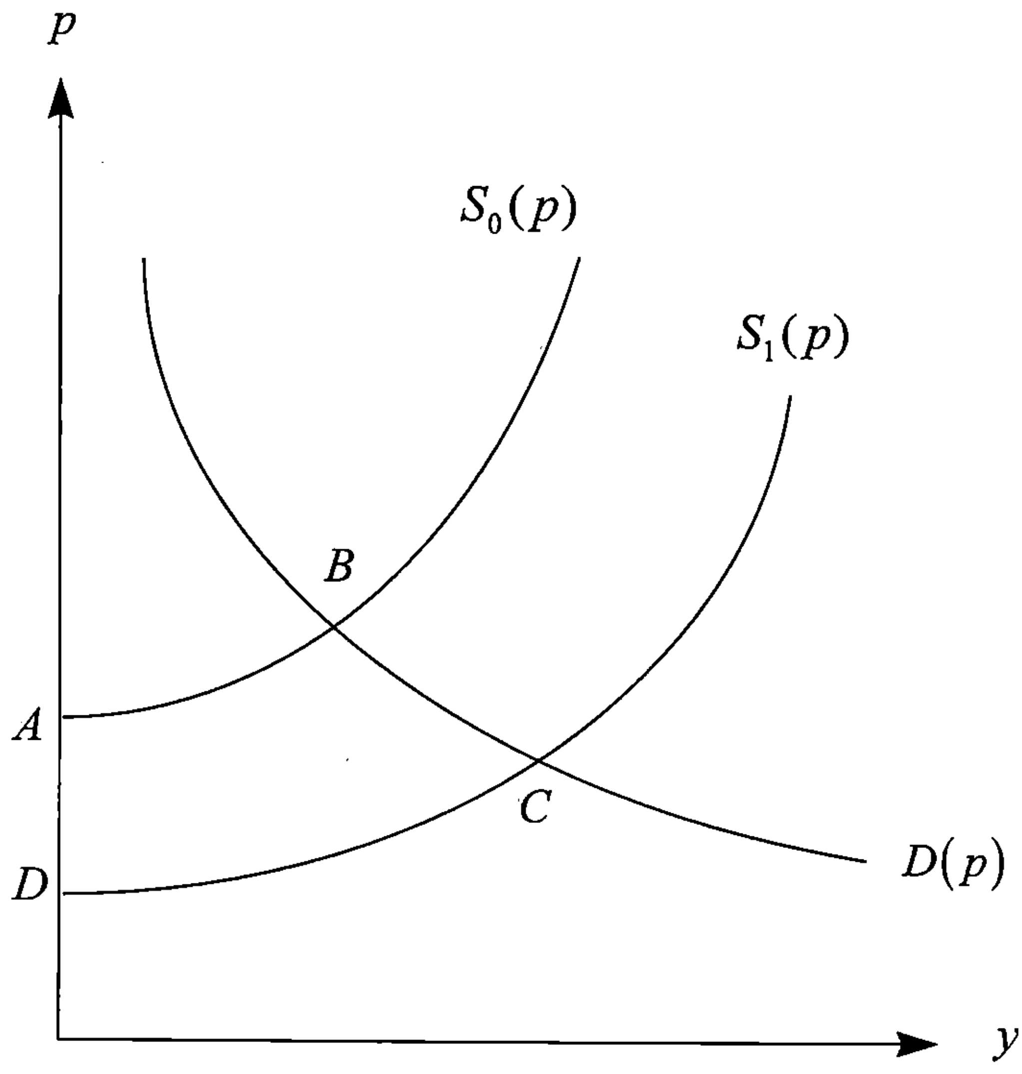

Figure 2. Drastic and Non-Drastic Innovations: the Output Market

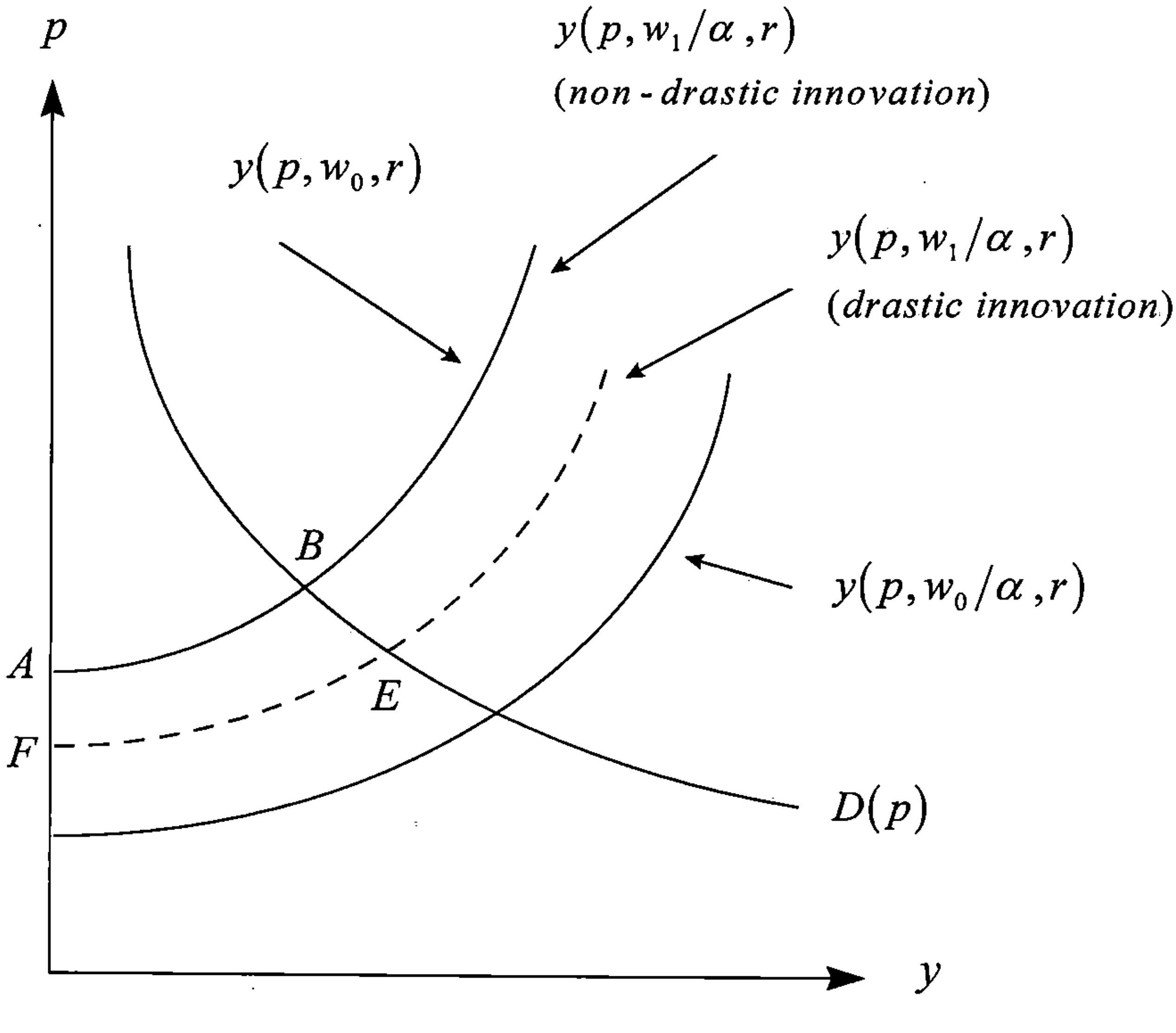

Figure 3. Non-Drastic Innovation: the Input Market

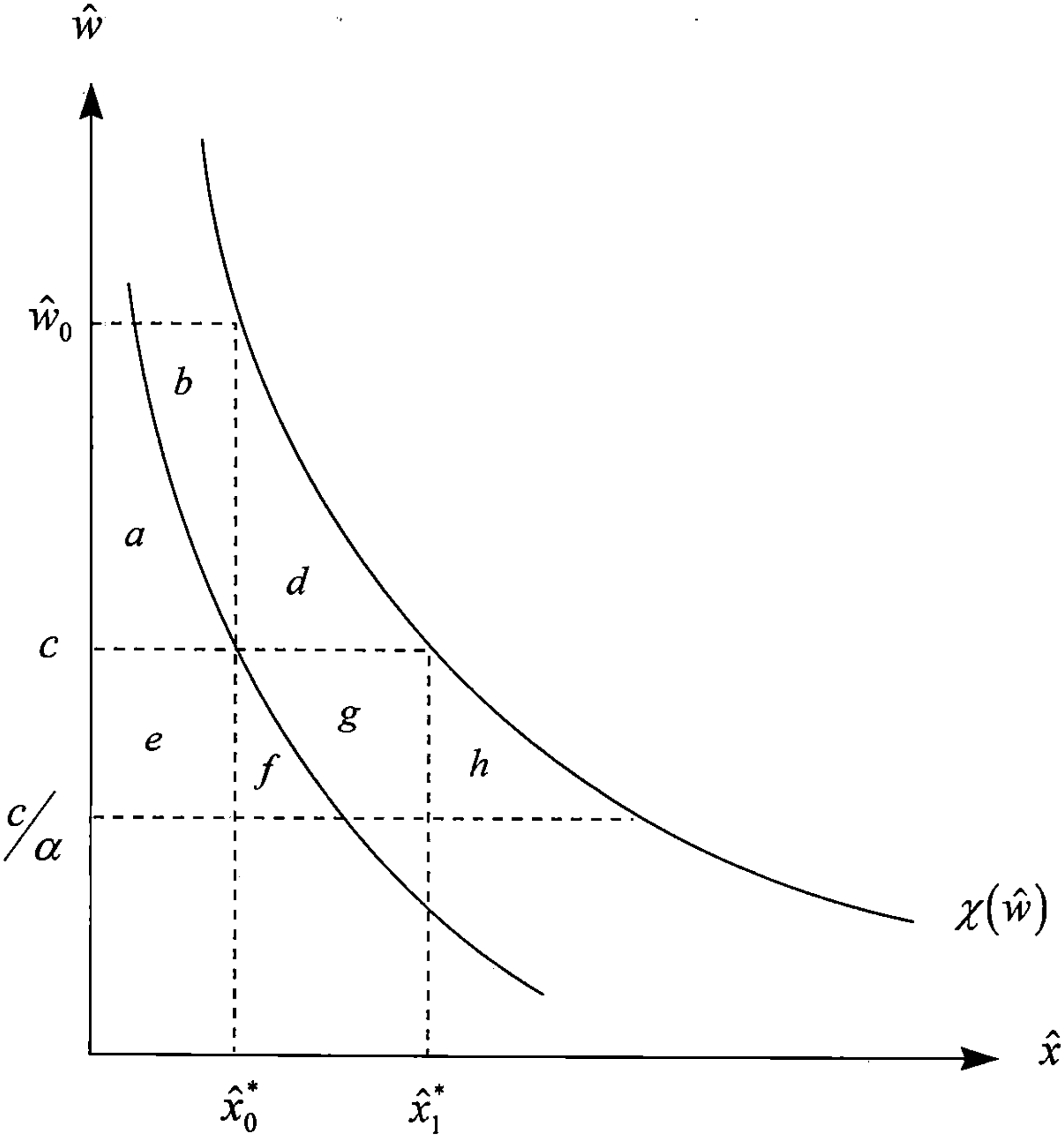

Figure 4. Drastic Innovation: the Input Market