Returns to Public Investments in Agriculture with Imperfect Downstream Competition

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A multiple-market framework is developed to measure the size and distribution of research benefits. The model considers an upstream raw product market and a downstream finished product market and allows for imperfect competition in the intermediary food-processing sector. A central conceptual result is derived: an increase in raw product output is a sufficient condition for cost-reducing innovations in the farm sector to increase social welfare. A special case of linear farm supply and isoelastic processing production functions reveals that necessary conditions for welfare to decrease are a convergent farm supply shift, an oligopsonistic upstream market configuration, and increasing returns-to-scale processing technology.

Key words: imperfect competition, oligopoly, oligopsony, research benefits.

A basic goal of public agricultural research is to reduce the costs of farm production. Toward this end, governments have invested considerable resources to improve basic scientific knowledge, develop novel technologies, and facilitate the adoption of modern plant varieties and farming methods. Economists have generally concluded that public investments in agriculture have achieved remarkable success in lowering the marginal cost of farm production, due in large part to the effectiveness of land grant research and extension activities (Chavas and Cox, Cochrane). As a result of these cost changes, public agricultural investments have been shown to yield impressive social rates of return in numerous studies (for a survey of this literature, see Alston, Norton, and Pardey).

Several recent papers have shown that imperfect competition in the downstream processing sector can affect both the size and the distribution of welfare changes. Dryburgh and Doyle consider the impact of technical innovation in a multimarket study of the British dairy industry under alternate downstream industry conditions of monopoly, monopsony, and perfect competition and find that research gains are smaller under monopoly. Huang and Sexton measure market power in the Taiwan tomato processing industry and use conjectural elasticity parameters to compare returns to mechanical tomato harvesting with a benchmark case of perfect competition. Recently, in the most thorough treatment of these issues to date, Alston, Sexton, and Zhang use a linear model with fixed proportions processing technology to examine the effect of imperfect competition in a multimarket framework. Their essential finding is that imperfect competition, in particular an oligopsony configuration, has a significant effect on the distribution of research benefits and a lesser impact on the corresponding total welfare change.

The studies to date on research benefits in imperfectly competitive markets have generally specified the effects of public research with parallel or proportional shifts in farm supply. The remaining possibility, that of convergent shifts, is an interesting omission in the literature. Convergent shifts, which make the farm supply function more inelastic, have been considered previously by Lindner and Jarrett in the competitive case; however, supply shifts that increase the slope of the farm supply relation have particularly profound implications under oligopsony.

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Other economists have noted that downward shifts in farm supply can reduce raw product use and increase farm prices in oligopsonistic industries. In particular, Chen and Lent find that an increase in the slope of the farm supply function is a necessary condition for a downward farm supply shift to reduce industry output. Hamilton and Sunding derive a similar result for convergent supply shifts in long-run oligopsony equilibria and detail how farm innovation can affect downstream concentration and market power. Our analysis extends this research, while recasting some of its major insights, by considering a more general theoretic framework and addressing the social welfare implications of convergent shifts in farm supply.

This article develops a framework for the measurement of research benefits that is more general than other analyses in the literature to date. We consider three extensions simultaneously: (*i*) a wider variety of farm supply shifts, (*ii*) a general specification of demand and farm cost functions, and (*iii*) a nondegenerate food processing production function that allows for various parameterizations of returns to scale. The analysis leads to several fundamental observations regarding the marginal welfare impacts of cost-reducing farm investments. When all markets are perfectly competitive, we show that a reduction in the cost of producing the status quo level of farm output is both a necessary and a sufficient condition for an increase in social welfare. Under conditions of imperfect competition, however, we uncover a result that underscores the importance of downstream market structure: Social welfare can decrease even when innovation reduces the cost of producing the status quo level of farm output. We demonstrate that welfare can decrease in response to innovation that lowers farm production costs only if the farm supply shift is convergent and the upstream raw product market is characterized by oligopsony. Conversely, we also show that an increase in farm output is a sufficient condition for a cost-reducing farm supply shift to increase social welfare.

In the final section, the general results of the model are made more transparent by considering a special case of linear farm supply and isoelastic processing production technology. Another necessary condition emerges for public research to reduce social welfare in this case: the food processing technology must exhibit increasing returns to scale. Thus, the three modifications made here to the more usual methods of evaluating research benefits provide a significant conceptual payoff.

The Model

Consider an agricultural economy consisting of a raw product market and a finished product market. The model is comprised of three types of agents (farmers, processors, and consumers) and two markets (a raw product market among farmers and processors and a finished product market among processors and consumers).

The processing industry is comprised of n firms. The raw product use of processor i is denoted x_i and the total raw product use in the industry is $X = \Sigma_{i=1}^{n} x_i$. Similarly, y_i represents the output of a single processing firm and aggregate output of the finished product is $Y = \Sigma_{i=1}^{n} y_i$. The production function of processor i is $y_i = f(x_i)$, where $f_i'(x_i) > 0$ and $f_i''(x_i) \leq 0$.[1] The consumer price is given by the inverse demand function for the final product, $P(Y)$, with $P_Y(Y) < 0$. The farm price is given by the inverse supply function for the raw product, $W(X; \theta)$, where θ is a shift parameter that represents the level of public agricultural investment. The farm supply function satisfies $W_X(X; \theta) > 0$ and, without loss of generality, we denote a downward shift in farm supply by the condition $W_\theta(X; \theta) < 0$. Strategic interaction among processors in the model is described by the conjectural variations parameters $\delta_i = dY/dy_i$ and $\gamma_i = dX/dx_i$, where δ_i and γ_i are assumed to be constant.

The processor profit function is expressed as

$$(1) \qquad \pi_i(x_i; \theta) = P\left[\sum_{i=1}^{n} f_i(x_i)\right] f_i(x_i) - W(X; \theta)x_i$$

which is defined completely over the input choice of the firm, x_i, and the exogenous policy parameter, θ. Expression (1) has the following first-order condition:[2]

[1] We consider the case of a single input to make the effects of a farm supply shift more transparent. An extension to the case of multiple inputs would be relatively straightforward.

[2] For notational convenience, we drop all arguments from the equations. Industry derivatives are denoted with subscripts, while the individual output effect of a representative processor is denoted with a prime.

$$\Phi(x_i\theta) \equiv Pf_i' + \delta_i p_y f_i' \mathbf{f}_i - W - \gamma_i W_x x_i = 0. \tag{2}$$

The market equilibrium in the processing industry is thus described by $4 + 2n$ equations:

$$\Phi_i(x_i; \theta) = 0, \qquad i = 1, 2, \ldots, n \tag{3}$$

$$y_i = f_i(x_i), \qquad i = 1, 2, \ldots, n \tag{4}$$

$$Y = \sum_{i=1}^{n} y_i \tag{5}$$

$$X = \sum_{i=1}^{n} x_i \tag{6}$$

$$P = P(Y) \tag{7}$$

$$W = w(X; \theta). \tag{8}$$

The equilibrium is characterized completely by the solutions $\{x_i, \mathrm{i} = 1, 2, \ldots, n\}$ in equation (3). That is, given the solutions in equation (3), equation (4) determines $\{y_i, i = 1, 2, \ldots, n\}$, equation (5) determines Y, equation (6) determines X, and equations (7) and (8), respectively, define the market prices P and W. The comparative statics results for an exogenous shift in the parameter θ are therefore captured entirely by the solutions to equation (3).

Confining attention to symmetric processor equilibria, equation (5) can be expressed as $Y = ny$ and equation (6) can be expressed as $X = nx$. Substituting equations (5) and (6) in equation (3), making use of equations (4), (7), and (8), the first-order condition of a representative processor is

$$\begin{aligned} \Phi(x, n, \theta) &= P[nf(x)]f'(x) + \delta P_Y[nf(x)]f'(x) \\ &\quad \times f(x) - W(nx) - \gamma x W_X(nx) = 0. \end{aligned} \tag{9}$$

Converting the conjectural variations parameters into elasticity form, we obtain $\xi = \delta y/Y$ and $\omega = \gamma x/X$, where $\xi, \omega \in [0, 1]$, with a value of 0 representing competition and a value of 1 representing monopoly and monopsony conduct, respectively.[3]

First-order condition (9) can be expressed compactly as

$$Pf'\phi = W \tag{10}$$

where $\phi = (1 - \xi\eta)/(1 + \omega\epsilon)$ is an inverse measure of the processing market imperfection, $\eta = -P'Y/P$ is the absolute value of the output elasticity (or price flexibility) of demand, and $\epsilon = W'X/W$ is the output elasticity of supply. Smaller values of ϕ represent greater departures from perfect competition.[4] In the competitive case, a representative processor equates the marginal value product with the farm price in equation (10), whereas, in noncompetitive environments, the price of the farm product is less than the value of its marginal product in inverse proportion to the value of ϕ.

In general, analytic solutions to equation (9) are not possible. The effect of an arbitrary farm supply shift on the market equilibrium is therefore described using the implicit function theorem. Differentiating first-order condition (9) with respect to x, we have

$$\begin{aligned} \Phi_x &\equiv f''(P + n\xi P_Y f) \\ &\quad + n(f')^2[(1 + \xi)P_Y + \xi P_{YY} f] \\ &\quad - n[(1 + \omega)W_X + \omega X W_{XX}] < 0. \end{aligned} \tag{11}$$

Expression (11) is an industry equilibrium condition, which, in a linear economy with constant returns to scale, reduces to $\Phi_x = -n\Omega$, where $\Omega = [(1 + \xi)P_Y + (1 + \omega)W_X]$ is as derived analytically by Alston, Sexton, and Zhang.

The derivative of equation (9) with respect to θ is $\Phi_x \equiv -(W_\theta + \omega X W_{X\theta})$. Thus, in a market without oligopsony power, public research affects the first-order condition of a representative processor solely through the level effect in the farm supply function, W_θ, which corresponds, in the short run, to the change in the marginal cost of farming. In a noncompetitive raw product market, public investment also affects first-order condition (9) through the rotation effect, $W_{X\theta}$, or through changes in the slope of the farm supply function. In the terminology of Lindner and Jarrett, the rotational effect of a downward shift is "convergent" when $W_{X\theta} > 0$, and it is "divergent" in the opposite case.[5] The most com-

[3] The allowable degree of oligopoly power is limited in a model of imperfect competition by the condition that marginal revenue be positive. From first-order condition (9), this restriction implies $\xi < (1/\eta)$.

[4] Specifically, the value of ϕ ranges from 1 under competition to $(1 - \eta)/(1 + \epsilon) < 1$ under conditions of joint monopoly and monopsony power.

[5] Note that we define these terms at the equilibrium point. Generally, if the supply functions cross each other, the shift may be convergent for one range of values and divergent for another.

mon supply shifts specified in empirical work are parallel shifts ($W_\theta < 0$ and $W_{X\theta} = 0$) and proportional shifts ($W_\theta = W_{X\theta} X < 0$).

The effect of public investment on a representative processor's use of farm products is $dx/d\theta = -\Phi_\theta/\Phi_x$. Using the aggregation condition (6), public investment changes raw product use in a symmetric processing industry as

$$(12) \quad \frac{dX}{d\theta} = \frac{n(W_\theta + \omega X W_{X\theta})}{\Phi_x}$$

where the denominator is negative by the equilibrium condition (11). For the case of nonparallel shifts, expression (12) may be written as

$$(13) \quad \frac{dX}{d\theta} = \frac{nXW_{X\theta}(\epsilon_\theta + \omega)}{\Phi_x}$$

where $\epsilon_\theta = W_\theta/XW_{X\theta}$, the elasticity of the shift in farm supply, gives the proportional change in the level effect relative to the rotation effect of the farm supply shift. The shift elasticity may be interpreted in terms of changes in the marginal and average farm price. At the initial level of output, the marginal change in the farm price is $W_{X\theta}$, while the average change in the farm price is W_θ/X. Thus, the shift elasticity is the ratio of changes in the average and marginal farm price at the initial equilibrium point. If public research reduces the equilibrium farm price (i.e., $W_\theta < 0$), the shift elasticity is positive for divergent shifts but negative for convergent shifts in farm supply.

Farm output can decrease in response to public research only when the shift elasticity is negative. In expression (13), farm output increases in response to a parallel or divergent shift in farm supply, regardless of the form of competition, but decreases in response to a convergent shift if $|\epsilon_\theta| < \omega$.[6] In the next section, our discussion reveals that the shift elasticity, or, more precisely, the sign of the rotation effect, $W_{X\theta}$, provides a relevant focus for the empirical investigation of research benefits in noncompetitive food processing environments.

[6] Chen and Lent derive a similar condition for a supply disturbance to decrease raw product use under oligopsony.

Sectoral Impacts of Public Research

In this section, we describe the effect of an arbitrary farm supply shift on farm surplus, processor surplus, and consumer surplus under various industry configurations in the processing sector. We first analyze the effect of public research on farm surplus and, in particular, on changes in the total cost of farming associated with agricultural innovation.

At the initial equilibrium point, the total variable cost of farm production is

$$(14) \quad TC(X; \theta) = \int_0^{X(\theta)} W(Z, \theta)\, dZ$$

which implies that public research changes total farm production costs as follows:

$$(15) \quad TC_\theta = W\frac{dX}{d\theta} + \int_0^X W_\theta(Z, \theta)\, dZ.$$

The first term after the equality in equation (15) is the change in production costs associated with the change in output, while the integral represents the change in the cost of producing the status quo level of output. That is, the integrand gives the distance between the initial and postresearch farm supply curves. Given that the intent of public research is to lower farm production costs, we confine attention to the case where the integral in equation (15) has a negative value, thereby eliminating from consideration public investments that increase the total cost of producing the status quo level of output.[7] Even with such a restriction, the effect of public research on farm production costs is potentially ambiguous: the cost of producing the *ex ante* output level declines but more units may be produced *ex post*.

In the empirical examination of research benefits, perhaps the greatest challenge is to measure the change in production costs along the entire length of the initial supply curve. In principle, this change is measurable if the functional form of the farm supply curve and the type of shift are known. Alternatively, it is also possible to estimate the change in the supply relation nonparametrically, using the

[7] Notice, however, that our methodology extends quite readily to other interventions, such as environmental regulations, that increase the total cost of farm production.

microparameter method described by Sunding.[8]

We next examine the effect of public research on farm surplus. Farm surplus is given as

$$FS(\theta) \equiv W(X, \theta)X - \int_0^{X(\theta)} W(Z, \theta)\, dZ.$$

It follows that the effect of public investment on farm surplus is

$$\text{(16)} \quad \frac{dFS}{d\theta} = W_X X\left(\frac{dX}{d\theta}\right) + W_\theta X - \int_0^X W_\theta(Z, \theta)\, dZ.$$

The effect of public research on farm surplus in equation (16) is ambiguous and depends on supply and demand conditions, the number of processing firms, the nature of competition in the processing industry, and the level and rotation effect of the shift in farm supply. For the case of a parallel supply shift, the last two terms cancel in equation (16) and farm surplus increases if and only if raw product use increases. From equation (12), raw product use always increases in response to a parallel shift, whereupon farm surplus unambiguously increases, regardless of the degree of structural competitiveness in the processing industry. For a divergent shift, the value of W_θ is greater at the equilibrium point than at lower output levels, which implies that the sum of the last two terms in equation (16) is negative. Thus, farm surplus can decline even when raw product use increases if public investment induces a divergent shift of farm supply. For a convergent shift, the value of W_θ is smaller at the equilibrium point than at lower levels of output, and the sum of the last two terms in equation (16) is positive. Hence, an increase in raw product output is sufficient for an increase in farm surplus following a convergent shift. Notice, however, that raw product use can decline in equation (12) for a convergent shift under conditions of oligopsony. With an oligopsonistic upstream raw product market, the change in farm surplus following a convergent shift depends on the relative magnitudes of the changes in farm output and farm production costs.

These findings relate to the empirical literature on changes in farm surplus under perfect competition. In the perfectly competitive case, equation (16) implies that a necessary condition for farm surplus to decrease is that the farm supply shift is divergent, a familiar result to studies that specify proportional farm supply shifts in the measurement of research benefits.

Processor surplus is defined as $PS(\theta) \equiv P[Y(\theta)]Y(\theta) - W(X;\ \theta)X(\theta)$. Differentiation of the processor surplus measure with respect to θ yields

$$\frac{dPS}{d\theta} = (P + P_Y Y)\left(\frac{dY}{d\theta}\right) - W_\theta X - (W + W_X X)\left(\frac{dX}{d\theta}\right).$$

Making use of the first-order condition (9) and the relationship $dY/d\theta = f'(dX/d\theta)$, it follows that

$$\text{(17)} \quad \frac{dPS}{d\theta} = [f' P_Y Y(1 - \xi) - W_X X(1 - \omega)] \times \left(\frac{dX}{d\theta}\right) - W_\theta X.$$

In the case of joint monopoly and monopsony in the processing industry, the first term is zero by the envelope theorem, and public investment unambiguously increases processor surplus. For all other industry configurations, expression (17) indicates that the change in output affects processor surplus, as the first term in equation (17) has the opposite sign of $dX/d\theta$. Thus, a contraction of raw product use is a sufficient condition for the farm supply shift to increase processor surplus. If raw product use increases in response to the shift, such as in the case of a parallel farm supply shift, the effect of public investment on processor surplus is determined by two countervailing factors. The downward shift in farm supply directly increases processor surplus through the last term in equation (17). However, the shift also affects processor surplus through the first term in equation (17), as an increase in aggregate raw product use increases the equilibrium price of the raw product and decreases the equilibrium price of the fin-

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[8] This method decomposes the initial supply curve into its constituent regional components (e.g., each point on the supply curve corresponds to production costs in a defined region) and calculates changes in production costs for each region as a function of changes in crop yields and per acre production costs.

ished product. This latter effect is stronger when oligopoly and oligopsony power is small and when the farm supply shift is divergent.[9]

Consumer surplus is defined as

$$CS(\theta) \equiv \int_0^{Y(\theta)} P(Z)\,dZ - P[Y(\theta)]Y(\theta).$$

Differentiation with respect to θ yields $dCS/d\theta = -P_Y Y(dY/d\theta)$. Making the substitution $dY/d\theta = f'(dX/d\theta)$, we have

$$(18)\quad \frac{dCS}{d\theta} = -P_Y Y f'\left(\frac{dX}{d\theta}\right).$$

The change in consumer surplus has the same sign as the change in raw product use in equation (12). This result indicates once again the importance of the term $W_{X\theta}$ in determining the distribution of research benefits in noncompetitive environments. Under perfect competition in the processing industry, consumer surplus increases for any downward shift in farm supply, regardless of the rotation effect, as competitive processors expand raw product use in response to the shift. In noncompetitive processing environments, public research increases consumer surplus when the farm supply shift is parallel or proportional, but immiserates consumers for convergent shifts that induce a contraction of raw product use in equation (12).

Public Research and Social Benefits

Social benefit, the sum of consumer, processor, and farm surplus, is given by

$$SB(\theta) \equiv \int_0^{Y(\theta)} P(Z)\,dZ - \int_0^{X(\theta)} W(Z;\theta)\,dZ.$$

Differentiating social benefit with respect to θ and simplifying yields

$$(19)\quad \frac{dSB}{d\theta} = (Pf' - W)\left(\frac{dX}{d\theta}\right) - \int_0^X W_\theta(Z;\theta)\,dZ.$$

In response to public innovation, social benefit increases in equation (19) following an expansion of raw product use and a decrease in the status quo costs of farm production. In a competitive food processing environment, the marginal value product of farm output equals the raw product price by first-order condition (9), which implies that the change in social benefit is equal to the reduction in total farm production costs at the initial equilibrium point. Thus, under conditions of perfect competition, a reduction in farm production costs at the initial equilibrium point is both a necessary and a sufficient condition for public research to increase social benefit.[10] When the processing sector is imperfectly competitive, equation (19) uncovers a fundamental result in public research: social welfare can decrease if $dX/d\theta < 0$. Thus, from equation (12), a perverse welfare result can emerge only in the case of a convergent farm supply shift.

This point is particularly interesting given the typical specifications of supply functions employed in empirical models of research benefits. Consider, for example, the following commonly specified inverse supply functions:

$$W(X, \theta) = \theta + \alpha X$$
$$W(X, \theta) = \alpha + \theta X$$
$$W(X, \theta) = \theta(\alpha + \beta X)$$
$$W(X, \theta) = \theta X^\alpha$$
$$W(X, \theta) = \alpha X^\theta$$
$$W(X, \theta) = (\theta X)^\alpha$$

where $d\theta < 0$ for a downward shift. Each of these functions precludes the possibility that $W_{X\theta} > 0$, and thus rule out, a priori, the type of effects that result from convergent shifts; these include a potential contraction of industry output and a concomitant decrease in social welfare.

Lindner and Jarrett and others have recognized the potential for public research to induce convergent farm supply shifts. The types of innovations most likely to result in convergent shifts are those that lower the costs of producing the status quo level of farm out-

[9] The analysis of processor surplus in the competitive case provides an interesting point of comparison between our approach and the case of fixed proportions production technology. The specification of a fixed input-output ratio in the processing sector restricts marginal profit to be zero under perfect competition, which rules out the possibility of fixed costs. Our choice of a more general production function leaves open the possibility that competitive processors earn positive profits in a short-run equilibrium and/or that fixed costs exist in the processing sector.

[10] This result also appears in Sunding.

put but increase the share of fixed costs in the crop budget. These changes reduce farm costs while simultaneously making the farm supply function less elastic. Indeed, one of the most celebrated analyses of research benefits alludes to just such an outcome. In their 1970 analysis of research benefits for the mechanical tomato harvester in California, Schmitz and Seckler find that adoption of the harvester reduced harvest labor requirements and variable production costs while increasing fixed costs. Subsequently, Just and Chern concluded that the adoption of the tomato harvester made the farm supply relation more inelastic and, hence, resulted in a convergent shift.[11]

The Case of Linear Supply and Isoelastic Production Technology

The methodological approach we have outlined employs general specifications of supply, demand, and processor production relationships. A special case of this framework, therefore, is the linear economy with fixed proportions processing technology pursued by Alston, Sexton, and Zhang. In this section, we present a special case that extends their analysis but which leads to quite different conclusions. In particular, we follow Alston, Sexton, and Zhang by specifying a linear farm supply curve but consider a more general, isoelastic food production technology. We also maintain a more general demand function, though this difference is of little import. The implication of the special case is that alternative specifications of the downstream production technology produce results that are fundamentally different from the case of fixed proportions, which clarifies an important and heretofore unrecognized role of scale economies in the processing sector. The results underscore our earlier observation that the relationship between farm supply shifts and research returns is considerably richer than previously recognized.

For analytic convenience, we consider a linear farm supply function and confine attention to the case of a competitive downstream finished products market.[12] As in the previous section, inverse demand is $P(Y)$, while the farm supply function is given by

$$(20) \quad W(X;\, \theta) = b(\theta) + \beta(\theta)X,$$

where the slope and intercept of the supply function, $\beta(\theta)$ and $b(\theta)$ respectively, are, at least potentially, affected by public research. At an initial equilibrium point, X^*, we can completely characterize a downward vertical shift in farm supply by the condition $W_\theta(X^*) = b_\theta + \beta_\theta X^* < 0$, while a rotation effect in the farm supply function is captured by the condition $W_{X\theta} = \beta_\theta$. Familiar supply shifts in empirical research include the parallel downward shift, which satisfies bq < 0 and $\beta_\theta = 0$, and the proportional divergent (or pivotal) shift, which satisfies $b_\theta = 0$ and $\beta_\theta < 0$. The other possibility we consider is that of a convergent shift, which is characterized by the ons $b_\theta < 0$, $\beta_\theta > 0$, and $b_\theta + \beta_\theta X^* < 0$.

The technology of a representative processor is given by the following isoelastic production function:

$$(21) \quad y = f(x) = Ax^\alpha$$

where α is the production elasticity. For alternative values of the production elasticity, equation (21) reduces to various processing situations associated with increasing returns to scale ($\alpha > 1$), decreasing returns to scale ($\alpha < 1$), and fixed proportions ($\alpha = 1$).

Using equation (20), the first-order condition (9) becomes

$$(22) \quad \Phi = Pf' - b - \beta(1 + \omega)X = 0.$$

By equation (11), the equilibrium condition is

$$(23) \quad \Phi_x = Pf'' + nP_Y(f')^2 - n\beta(1 + \omega) < 0.$$

For isoelastic production technology (21), substituting $f' = \alpha f/x$ and $f'' = (\alpha - 1)f'/x$ in equation (23) and simplifying yields

$$(24) \quad \Phi_x = \Psi/x < 0$$

where $\Psi = \{Pf'[\alpha(1 - \eta) - 1] - \beta X(1 +$

[11] We should emphasize that the adoption of the tomato harvester increased social welfare, because the large downward-level effect of the farm supply curve dominated the rotation effect of the convergent shift. The point is, rather, that convergent shifts are an empirical possibility.

[12] These specifications do not qualitatively affect the results described below. The objective here is to examine research returns in an analytically convenient multimarket framework, the simplest of which combines a generalized production function in the processing industry with a competitive market-clearing condition in the downstream finished product industry.

$\omega)\}$. Applying the implicit function theorem to equation (22), we obtain

$$(25)\quad \frac{dX}{d\theta} = \frac{X[b_\theta + \beta_\theta X(1 + \omega)]}{\Psi}.$$

From equation (20), the total cost of farm production is the area under the supply function

$$TC(X) = \int_0^X (b + \beta Z)\, dZ.$$

Hence, in response to public innovation, the change in the total cost of producing the status quo level of farm output is

$$(26)\quad \int_0^X W_\theta(Z, \theta)\, dZ = (b_\theta X^2 + \beta_\theta X^2)/2.$$

In equation (26), the total cost of producing the status quo level of farm output decreases for a convergent shift in farm supply ($\beta_\theta \geq 0$), as $(b_\theta + \beta_\theta X/2) < (b_\theta + \beta_\theta X) < 0$. Total farming costs also decrease for a parallel or proportional farm supply shift, although a divergent shift that reduces the equilibrium farm price may increase the cost of producing the status quo level of farm output. This result occurs if $b_\theta > 0$ and $-\beta_\theta X/2 < b_\theta < -\beta_\theta$.

Substituting equation (25) and equation (26) into equation (19) for the change in social benefit yields

$$(27)\quad \frac{dSB}{d\theta} = X\{2\omega\beta X[b_\theta + \beta_\theta X(1 + \omega)] - \Psi(2b_\theta + \beta_\theta X)\}/2\psi$$

where the denominator is negative by equation (24). In a competitive environment, equation (27) reduces to $dSB/d\theta = -X(b_\theta + \beta_\theta X/2)$, which is positive for a cost-decreasing farm supply shift, as in the general model. It follows directly that public research reduces social benefit only in the case of an upstream oligopsony configuration and a convergent farm supply shift.

Evaluating equation (27) at the equilibrium point and substituting the definitions $W_\theta = b_\theta + \beta_\theta X^*$ and $W_{X\theta} = \beta_\theta$, yields, after some simplification,

$$(28)\quad \frac{dSB}{d\theta} = W_\theta X[2(\omega\beta X - \Psi) + \epsilon_\theta(2\omega^2\beta X + \Psi)]/2\Psi$$

where the shift elasticity, ϵ_θ, is as described in the previous section. Inspection of equation (28) reveals that public research increases social benefit when the term in square brackets is positive. The first term in this bracket is positive by equation (24). Thus, for a convergent shift of farm supply ($\epsilon_\theta < 0$), social welfare can only decrease when the shift elasticity is relatively large (in absolute value) and when market circumstances satisfy the inequality $\Psi + 2(\omega)^2\beta X^* > 0$. Substitution of Ψ reveals that a necessary condition for a perverse welfare effect to occur in equation (28) is

$$(29)\quad Pf'[\alpha(1 - \eta) - 1] > \beta X^*[(1 - \omega^2) + (1 - \omega)].$$

Noting that $\omega \leq 1$, it follows immediately that the right-hand side of equation (29) is (at least weakly) positive. Therefore, necessary conditions for a convergent farm supply shift to reduce social benefits are $\omega > 0$ and $\alpha(1 - \eta) > 1$.

The implication of the special case is that a convergent farm supply shift can reduce social welfare only when the processing technology satisfies $\alpha > 1$, which corresponds to a situation of increasing returns to scale in the food processing industry. Moreover, the range of circumstances in which public research yields negative social returns increases with the value of α. This finding highlights the potential quantitative and qualitative bias in the calculation of social benefits when a degenerate processing production function is specified in food processing environments that are not, in fact, characterized by constant returns to scale.

Conclusion

This article develops a general framework for calculating of the size and distribution of research benefits. The framework distinguishes between the farm product and final product markets with a processing production function, employs general supply and demand functions, and considers broad classes of farm supply shifts.

The results reinforce the importance of as-

sumptions about competitive conditions and the specification of supply shifts when measuring the size and distribution of research benefits. In particular, when the downstream processing industry is imperfectly competitive, the welfare implications of cost-reducing innovation are sensitive to changes in the slope of the farm supply relation. Public investment that lowers the total cost of farming always increases aggregate welfare under perfect competition but may actually reduce welfare for convergent shifts when the downstream food processing industry is imperfectly competitive.

The nature of food processing technology is also important. A special case of the model reveals that necessary conditions for public research to result in perverse welfare changes is an oligopsony upstream market configuration and increasing returns to scale in the processing industry. The potential for substantial scale economies in the highly concentrated food processing sector favors the implementation of more general farm supply shifts and more flexible processor production relationships in future analyses of research benefits.

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