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# Imperfect competition, functional forms, and the size and distribution of research benefits

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**Abstract**

The effects of functional forms for supply and demand on the size and distribution of the returns to research are examined under a range of forms of competition. Under perfect competition, the choice of functional form is relatively unimportant for the estimation of research benefits. Under imperfect competition, the combination of the choice of functional forms for supply and demand and the nature of the research-induced supply shift can have profound implications for the results. Functional form plays a much more important role than in the competitive model. The most important contrast is between the constant elasticity model and the linear model (along with various cases of a generalized linear model). These findings are illustrated using a combination of analytical results and numerical simulations. 

*Keywords:* Research benefits; Functional form; Imperfect competition

## 1. Introduction

Studies of the benefits from agricultural research generally assume perfectly competitive markets for agricultural inputs and outputs, and the effects of research are usually represented by a parallel shift of a linear supply function or a multiplicative shift of a constant-elasticity supply function. Such assumptions, made largely for analytical convenience in most cases, can have profound implications for the measured consequences of research. In a competitive market setting, assumptions about the functional forms of supply and demand are relatively unimportant, by themselves, but assumptions about the nature of the research-induced supply shift have major implications for total research benefits and, especially, the distribution of research benefits. Specifically, producers necessarily gain from a parallel research-induced supply shift but they lose from a proportional supply shift when demand is inelastic. These results, and others, have been documented comprehensively in an extensive literature, much of which was summarized by Alston et al. (1995).

One set of questions from this literature concerns the possibilities for using theory or econometrics to define or measure the functional form of supply and the research-induced supply shift. Econometricians have written much in recent years about testing specification choices and about diagnostic tests that can be used to evaluate choices of functional forms in

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supply and demand models. A critical problem, however, is that the data, (and thus the econometric tests), are relevant only for that region of the model where the data have been observed. And, typically, the data are so limited that it has been a challenge to establish whether, and how much, past research has affected supply, let alone to test curvature of that relationship that can be extrapolated across the extreme, theoretically (but not empirically) feasible set of prices and quantities. For these reasons, economists working in this area (e.g., Lindner and Jarrett, 1978; Rose, 1980; Alston et al., 1995; Wohlgenant, 1997) have reconciled themselves to being unable to determine empirically the form of the research-induced supply shift; assumptions will continue to be necessary. Given this situation, it is desirable to be able define sets of assumptions that, at a minimum, are not inconsistent with what is believed about the nature of supply functions and research-induced shifts in them. It is also useful to understand the implications of alternative sets of assumptions for measures of research benefits.

A second set of issues concerns the assumed form of competition. Most of the work on research benefits has assumed perfect competition. However, literature on the industrial organization of agricultural markets indicates that many markets exhibit structural characteristics at odds with the axioms of perfect competition (e.g., Connor et al., 1985; Rogers and Sexton, 1994), and several empirical studies have documented departures from competitive pricing in specific agricultural markets. Sexton and Lavoie (1999) provide a recent summary of this literature. Moreover, concentration in food markets is rising over time (Rogers, 1997), suggesting that issues of competition in agriculture will assume increasing importance over time.

A limited literature to date indicates that imperfect competition may have significant effects on the size and distribution of research benefits. Most of this literature, however, has assumed extreme forms of imperfect competition, with only a few studies (Huang and Sexton, 1996; Alston et al., 1997; Hamilton and Sunding, 1998) having used more realistic oligopoly/oligopsony models to explore the effects of imperfect competition on the size and distribution of research benefits. This literature, however, has not dealt adequately with the implications of different combinations of functional forms for supply and demand, different forms of research-induced supply shift, and the nature of competition for the size and distribution of research benefits.

The present paper combines the Huang and Sexton framework for measuring research benefits under general conditions of oligopoly or oligopsony or both with a rather general specification of the supply function that admits as special cases the typical linear/parallel shift and constant-elasticity/proportional shift specifications of supply. All the combinations of different functional forms and different forms of competition assumed in previous work are nested as special cases in this encompassing model. Thus, compared with previous work, we provide a more general analysis of the size and distribution of benefits from agricultural research, and offer some general conclusions about the implications of the form of market competition, combined with the nature of the research-induced supply shift, for measures of research benefits.

## 2. The scope of the study

At the center of the extensive literature on modeling agricultural research benefits is a partial equilibrium market model for a commodity, with competition in both factor and product markets. A research-induced technical change is modeled as a shift of the commodity supply function, and Marshallian producer and consumer surplus measures are used to evaluate the welfare consequences of the given supply shift.

Models have typically combined constant elasticity supply and demand functions with proportional supply shifts, or linear supply and demand functions with parallel supply shifts, with predictable consequences for the size and distribution of measured research benefits. A further problem with either of these sets of assumptions is that the models become implausible as we extrapolate back to the price axis, as is necessary for measuring producer surplus. If we assume a linear model and supply is inelastic, positive quantities are supplied at negative prices, and all constant-elasticity supply functions pass through the origin, most economists would be more comfortable with a supply function characterized by a positive shut-down price.

A supply model that avoids these problems, and nests the two most common alternatives (among others) as special cases, was suggested by Lynam and Jones (1984) and by Pachico et al. (1987). This model is

$$Q = B(W - b)^{\rho},$$

where $Q$ is the quantity supplied, $W$ is the price, and $b$, $B$, and $\rho$ are the parameters, all of which are non-negative.[2] The same model in price-dependent form is

$$W = b + \beta Q^{1/\rho},$$

where $\beta = B^{-1/\rho}$. Given knowledge of $b$, the shut-down price, the other parameters can be calculated from the elasticity of supply, $\epsilon$, and the price and quantity at the initial equilibrium. This model contains as special cases the constant elasticity model ($b = 0$) and the linear model ($\rho = 1$). It also includes other familiar models as special cases, such as the square-root or quadratic models.

Now, to represent research-induced technical change, we can make any or all of the parameters of this model functions of the quantity of research, $R$, as follows:

$$W = b(R) + \beta(R) Q^{1/\rho(R)}.$$

The conventional models can readily be seen as special cases. For instance, in the linear model, a parallel research-induced supply shift is represented by reducing the price-intercept parameter, $b$, holding the slope, $\beta$, constant; a pivotal shift (a proportional shift in the quantity direction) is represented by reducing the slope parameter, $\beta$, while holding the intercept, $b$, constant; and a proportional shift in the price direction is represented by reducing both $b$ and $\beta$ by the same proportion. All of these cases have been considered previously (e.g., see Lindner and Jarrett, 1978), but most studies have used a parallel shift with a linear model.

In the constant-elasticity model, previous studies have almost always assumed a multiplicative shift, so that the model can be represented as being linear in logarithms. This case is given by combining $b = 0$ and $\rho = \epsilon$ with a research-induced reduction in $\beta$. But the more general model also allows for a vertically parallel research-induced shift in a supply function that is of the constant-elasticity form — a constant elasticity with respect to the adjusted price, $W - b(R)$, given by a reduction in the shut-down price, $b(R)$. The above model also allows for more-general shifts of more-general supply functions, by combining changes in $b(R)$ and $\beta(R)$.[3]

In the analysis below, this relatively general supply model is used to evaluate the size and distribution of the benefits from research under different forms of competition. Huang and Sexton (1996) set forth a conjectural variations oligopoly/oligopsony model that admits monopoly, monopsony, and perfect competition as special cases. Alston et al. (1997) used this model to study the effects on the size and distribution of research benefits of a wide range of market behaviors, for pivotal or parallel research-induced supply shifts in the context of a linear supply and demand setting. Here, we extend the work of Alston et al. (1997) to consider the alternative functional forms in a model that nests the cases they considered as special cases. To keep the analysis manageable we do, however, retain several simplifying assumptions made by Alston et al., 1997. We focus on the case of a single homogeneous processed farm product. We further assume fixed proportions between the raw product and processing inputs and a constant returns to scale processing technology, and a closed economy with no government intervention in the commodity market.

## 3. The basic imperfect competition model

Following Huang and Sexton (1996) and Alston et al. (1997), we model research benefits under imperfect competition through use of the so-called 'conjectural variation'. We consider a model where all marketing functions are subsumed within a single sector called processing and develop the model for the case of homogeneous, quantity-setting firms. The inverse retail demand function for the finished product is represented by

$$P = P(Q^{\mathrm{r}} | X) \tag{1}$$

where $P$ represents the market price, $Q^{\mathrm{r}}$ is the market

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[2] As well as being useful for defining sets of assumptions about supply functions and research-induced supply shifts, this model could be useful for empirical econometric work, to test among alternatives, since it nests the typical models as special cases.

[3] The model also allows for a research-induced change in the exponent parameter, $\rho(R)$. This possibility is noted here only for generality, and not considered further.

quantity of processed product, and $X$ denotes demand shifters. Farm supply of the raw commodity is expressed in inverse form as

$$W = W(Q^{\mathrm{f}}|Y) \tag{2}$$

where $W$ is the farm price, $Q^{\mathrm{f}}$ is the market volume of raw product, and $Y$ denotes supply shifters.

Denote a representative firm's volume of raw product purchases by $q^{\mathrm{f}}$ For convenience, and without loss of generality, we define units so that $q^{\mathrm{r}} = q^{\mathrm{f}} = q$. Given the assumptions of fixed proportions between raw product and processing inputs, and constant returns to scale in processing, the processor's variable cost function can be written as

$$C = c(V)q^{\mathrm{f}} + Wq^{\mathrm{f}} \tag{3}$$

where $c(V)$ represents the constant processing costs per-unit of raw product processed, and $V$ represents the vector of prices for variable processing inputs. The processor's profit function, $\pi$, can then be expressed as

$$\pi = P(Q^{\mathrm{r}})q^{r} - (W(Q^{\mathrm{f}}) + c)q^{\mathrm{f}}, \tag{4}$$

where $q^{\mathrm{r}}$ is the quantity of processed product produced. Notation for exogenous variables $X$, $Y$, and $V$ is henceforth suppressed.

The first-order necessary condition for maximizing Eq. (4) is

$$\begin{aligned}\frac{\partial \pi}{\partial q} &= P + P'(Q^{\mathrm{r}})\left(\frac{\partial Q^{\mathrm{r}}}{\partial q}\right)q - (W + c)\\ &\quad - W'(Q^{\mathrm{f}})\left(\frac{\partial Q^{\mathrm{f}}}{\partial q}\right)q = 0\end{aligned} \tag{5}$$

The processor's conjectural variations are $\lambda^{\mathrm{f}} = \partial Q^{\mathrm{f}}/\partial q$ and $\lambda^{\mathrm{r}} = \partial Q^{\mathrm{r}}/\partial q$. Eq. (5) can be written in elasticity form as

$$P\left[1 - \frac{\xi}{\eta_{\mathrm{r}}}\right] = W\left[1 + \frac{\theta}{\epsilon_{\mathrm{f}}}\right] + c \tag{6}$$

where $\epsilon_{\mathrm{f}} = (\partial Q/\partial W)(W/Q)$ is the market price elasticity of supply of the raw product, $\eta_{\mathrm{r}} = |(\partial Q/\partial P)(P/Q)|$ is the absolute value of the market price elasticity of demand for the processed product, $\theta = \lambda^{\mathrm{f}}(q/Q^{\mathrm{f}})$ and $\xi = \lambda^{\mathrm{r}}(q/Q^{r})$. The so-called 'conjectural elasticities', $\theta$ and $\xi$, range from 0, representing perfect competition, to 1 representing monopoly/monopsony. Intermediate values represent different forms of oligopoly/oligopsony competition, such as Cournot behavior, with higher values representing greater departures from competition.

As Wann and Sexton (1992) have noted, aggregation from the firm to the industry is accomplished readily, given the above model framework. Because firms produce a homogeneous product and have identical technologies, optimizing behavior compels that ex post all firms' conjectures are identical.

## 4. Explicit functional forms

In order to implement the above imperfect competition model we have to define explicit functional forms for the farm-product supply and retail demand equations.[4] In keeping with the above discussion, and treating supply and demand symmetrically, we can define general forms for price dependent supply and demand equations as

$$P = a - \alpha Q^{1/\sigma} \quad \text{retail demand,} \tag{7}$$

$$W = b + \beta Q^{1/\rho} \quad \text{farm supply.} \tag{8}$$

Restrictions on the parameters are needed to assure that these models represent well-behaved demand and supply functions. A sufficient condition is that all of the parameters are positive numbers. The set of restrictions used in the following analysis defines what we call the generalized linear model: it precludes the constant elasticity model.[5] The demand function is linear if $\sigma = 1$, strictly convex if $\sigma > 1$, and strictly concave if $\sigma < 1$. The supply function is linear if $\rho = 1$,

[4] An alternative to our approach would be to maintain general functions for demand and supply and conduct a comparative-static exercise using the methods suggested by Dixit (1986). Chen and Lent (1992) provide an example of this analysis in the context of oligopsony. However, as our analysis shows, most of the key measures of interest, such as the effect of research on farmer surplus and processor profits, do not have unambiguous signs, even for the model specified in (7) and (8). Thus, few general insights can be gleaned from such a generic approach. The more useful alternative is to work directly with the functional forms that researchers have used, or might easily use, in applied studies.

[5] The necessary restriction for a well-behaved demand function is weaker: the product, $\alpha\sigma$, must be a positive number. If both are positive ($\alpha > 0$ and $\sigma > 0$), the model nests the linear form (when $\sigma = 1$) but cannot nest the constant-elasticity model, and if both are negative ($\alpha < 0$ and $\sigma < 0$), the model nests the constant-elasticity form (when $a = 0$) but cannot nest the linear model.

strictly convex if $\rho < 1$, and strictly concave if $\rho > 1$. Further restrictions provide special cases of interest, since the generalized linear model nests forms such as linear ($\sigma = \rho = 1$), square-root ($\sigma = \rho = 2$) and quadratic ($\sigma = \rho = 0.5$).

Given our assumptions about the processing technology, we can write the aggregate variable processing cost as

$$C(Q) = cQ + WQ. \tag{9}$$

Combining equations (7), (8) and (9) with the market clearing condition in (6), one can solve for the effects of research-induced changes in the parameters of the supply function on prices, quantities, and economic welfare of producers, consumers, and processors. Analytical solutions for the price and quantity effects of supply shifts cannot be obtained for the model in its most general form. In order to be able to obtain analytical solutions, we work exclusively with the case where $\rho = \sigma$, so that both the farm supply and retail demand equations have the same quantity exponent. This does not mean that the two functions have the same elasticities, since the elasticities depend on the intercepts ($a$ and $b$) as well as the exponents.

## 5. Benefits from a parallel supply shift

We use superscript $c$ to denote variables under competitive conditions, and $m$ to denote variables under imperfectly competitive conditions. The prices and quantities at the competitive equilibrium are normalized by choosing $P_0^c = 1$, $Q_0^c = 1$, and, hence, $W_0^c = P_0^c - c = 1 - c$. Therefore, $a = 1 + \alpha$ and $b = 1 - c - \beta$. The elasticities of farm supply, $\epsilon_{\mathrm{f}}$, and retail demand, $\eta_{\mathrm{r}}$ (in absolute value), at the initial competitive equilibrium are then $\epsilon_{\mathrm{f}} = \sigma s/\beta$ and $\eta_{\mathrm{r}} = \sigma/\alpha$, where $s = 1 - c$ is the farm share of the retail price. When farm supply shifts down in parallel by $z$ per unit to $S_1$

$$W = b - z + \beta Q^{1/\sigma},$$

the new competitive equilibrium is given by

$$W_1^c = (b-z) + \beta(Q_1^c)^{1/\sigma};\ P_1^c = a - \alpha(Q_1^c)^{1/\sigma};$$
$$Q_1^c = \left[\frac{\alpha + \beta + z}{\alpha + \beta}\right]^{\sigma}$$

Total economic surplus, SB, increases by an amount equal to

$$\Delta\mathrm{SB}^c = \frac{\alpha + \beta}{1 + \sigma}\left[\left(\frac{\alpha + \beta + z}{\alpha + \beta}\right)^{1+\sigma} - 1\right] > 0.$$

The shares of these benefits going to consumers and producers ($S_{\mathrm{c}}^{\mathrm{c}}$ and $S_{\mathrm{f}}^{\mathrm{c}}$, respectively) are

$$S_{\mathrm{c}}^{\mathrm{c}} = \frac{\alpha}{\alpha + \beta} = \frac{\phi}{\phi + s},$$

and

$$S_{\mathrm{f}}^{\mathrm{c}} = \frac{\beta}{\alpha + \beta} = \frac{s}{\phi + s},$$

where $\phi = \epsilon_{\mathrm{f}}/\eta_{\mathrm{r}}$. The competitive processing sector captures none of the research benefit.

The imperfectly competitive equilibrium without the supply shift is given by

$$W_0^{\mathrm{m}} = b + \beta(Q_0^{\mathrm{m}})^{1/\sigma};\quad P_0^{\mathrm{m}} = a - \alpha(Q_0^{\mathrm{m}})^{1/\sigma};$$
$$Q_0^{\mathrm{m}} = \left[\frac{\alpha + \beta}{\Omega_1}\right]^{\sigma},$$

where $\Omega_1 = (1+\theta/\sigma)\beta + (1+\xi/\sigma)\alpha$. Output decreases with increases in either $\theta$ or $\xi$. Further, the effects of market power are determined jointly by $\theta$ and $\xi$ and the elasticities of the demand and supply curves as represented by parameters $\alpha$, $\beta$, and $\sigma$. For example, the more inelastic is supply (i.e., the greater is $\beta$ and/or the smaller is $\sigma$), the greater is the effect of buyer market power ($\theta$). Similarly, the greater is $\alpha$ or the smaller is $\sigma$, the more inelastic is the demand, and, therefore, the greater is the effect of seller market power ($\xi$).

When supply shifts down in parallel by $z$ per unit, the new equilibrium under imperfect competition is characterized by

$$W_1^{\mathrm{m}} = (b-z) + \beta(Q_1^{\mathrm{m}})^{1/\sigma};\quad P_1^{\mathrm{m}} = a - \alpha(Q_1^{\mathrm{m}})^{1/\sigma};$$
$$Q_1^{\mathrm{m}} = \left[\frac{\alpha + \beta + z}{\Omega_1}\right]^{\sigma}.$$

The output expansion is smaller under market power than under competition, since

$$\frac{\Delta Q^{\mathrm{m}}}{\Delta Q^{\mathrm{c}}} = \left[\frac{\alpha + \beta}{\Omega_1}\right]^{\sigma} < 1 \text{ if } \theta \text{ or } \xi > 0.$$

Total research benefits under imperfect competition are equal to the corresponding benefits under perfect competition minus any increase in the deadweight loss associated with market power caused by the research-induced supply shift (Alston et al., 1997). The induced change in the deadweight loss from imperfect competition is

$$\begin{aligned}\Delta\mathrm{DWL} &= \mathrm{DWL}_1^{\mathrm{m}} - \mathrm{DWL}_0^{\mathrm{m}}\\ &= \frac{\alpha+\beta}{1+\sigma}\left[\left(\frac{\alpha+\beta+z}{\alpha+\beta}\right)^{1+\sigma} - 1\right]\\ &\quad\times\left[1-\frac{(\alpha+\beta)^{\sigma}(\Omega_1+\xi\alpha+\theta\beta)}{\Omega_1^{1+\sigma}}\right]\\ &= \Delta\mathrm{SB}^{\mathrm{c}}\left[1-\frac{(\alpha+\beta)^{\sigma}(\Omega_1+\xi\alpha+\theta\beta)}{\Omega_1^{1+\sigma}}\right] > 0.\end{aligned}$$

Hence, the increase in total economic surplus from a parallel supply shift under imperfect competition is given by

$$\begin{aligned}\Delta\mathrm{SB}^{\mathrm{m}} &= \Delta\mathrm{SB}^{\mathrm{c}} - \Delta\mathrm{DWL}\\ &= \Delta\mathrm{SB}^{\mathrm{c}}\left[\frac{(\alpha+\beta)^{\sigma}(\Omega_1+\xi\alpha+\theta\beta)}{\Omega_1^{1+\sigma}}\right] < \Delta\mathrm{SB}^{\mathrm{c}},\end{aligned}$$

i.e., imperfect competition reduces benefits from a parallel research-induced supply shift relative to the competitive case.

The effect of market power on total benefits from research can be analyzed by defining $L = \Delta\mathrm{DWL}/\Delta\mathrm{SB}^{\mathrm{c}}$ which equals the proportion of benefits lost due to market power.

$$\begin{aligned}L &= \frac{\Delta\mathrm{DWL}}{\Delta\mathrm{SB}^{\mathrm{c}}} = 1-\frac{(\alpha+\beta)^{\sigma}(\Omega_1+\xi\alpha+\theta\beta)}{\Omega_1^{1+\sigma}}\\ &= 1-\frac{(\phi+s)^{\sigma}(\Omega_1^*+\xi\phi+\theta s)}{(\Omega_1^*)^{1+\sigma}} > 0,\end{aligned}$$

where $\Omega_1^* = (1+\theta/\sigma)s + (1+\xi/\sigma)\phi = \epsilon_{\mathrm{f}}\Omega_1$. Differentiating $L$ with respect to each of the parameters yields: $\mathrm{d}L/\mathrm{d}\phi > 0$ if $\xi > \theta$; $\mathrm{d}L/\mathrm{d}s \gtreqless 0$ if $\xi \gtreqless \theta$; $\mathrm{d}L/\mathrm{d}\xi > 0$; $\mathrm{d}L/\mathrm{d}\theta > 0$. These results for the generalized linear model with $\sigma = \rho$ are consistent with the linear model results for a parallel supply shift reported by Alston et al. (1997). It is not easy to sign $\mathrm{d}L/\mathrm{d}\sigma$ analytically, but extensive simulations indicate that $\mathrm{d}L/\mathrm{d}\sigma < 0$ (i.e., a bigger $\sigma$ results in a smaller deadweight loss from imperfect competition). This is so because a bigger $\sigma$ implies a more elastic supply and demand, and therefore diminishes processors' oligopsony or oligopoly power and results in a smaller deadweight loss.

The shares of research benefits under imperfect competition to processors ($S_{\mathrm{p}}^{\mathrm{m}}$), farmers($S_{\mathrm{f}}^{\mathrm{m}}$), and consumers ($S_{\mathrm{c}}^{\mathrm{m}}$) are as follows:

$$S_{\mathrm{p}}^{\mathrm{m}} = \frac{\Delta\Pi^{\mathrm{m}}}{\Delta\mathrm{SB}^{\mathrm{m}}} = \frac{(1+\sigma)(\xi\phi+\theta s)}{\sigma\Omega_2}, \text{ and } S_{\mathrm{p}}^{\mathrm{m}} > S_{\mathrm{p}}^{\mathrm{c}} = 0,$$

$$S_{\mathrm{f}}^{\mathrm{m}} = \frac{\Delta\mathrm{PS}^{\mathrm{m}}}{\Delta\mathrm{SB}^{\mathrm{m}}} = \frac{s}{\Omega_2} > 0 \text{ and } S_{\mathrm{f}}^{\mathrm{c}} > S_{\mathrm{f}}^{\mathrm{m}} > 0,$$

$$S_{\mathrm{c}}^{\mathrm{m}} = \frac{\Delta\mathrm{CS}^{\mathrm{m}}}{\Delta\mathrm{SB}^{\mathrm{m}}} = \frac{\phi}{\Omega_2} > 0, \text{ and } S_{\mathrm{c}}^{\mathrm{c}} > S_{\mathrm{c}}^{\mathrm{m}} > 0,$$

where $\Omega_2 = \Omega_1^* + \xi\phi + \theta s$ and $S_{\mathrm{p}}^{\mathrm{m}} + S_{\mathrm{f}}^{\mathrm{m}} + S_{\mathrm{c}}^{\mathrm{m}} = 1$. Thus, for the parallel supply shift processors, who capture no research benefits under perfect competition, are clearly better off under imperfect competition, while both farmers and consumers capture less benefit under imperfect competition.

Comparative-static results for the effects of processor market power on the distribution of benefits are intuitive, and identical to those derived by Alston et al. (1997) for their linear model, which is a special case of the model here. An increase in either of the market power indices ($\xi$ or $\theta$) results in an increase in the processors' share of benefits and a reduction in the shares of benefits going to both consumers and farmers; further, an increase in the curvature parameter ($\sigma = \rho$) implies more elastic supply and demand, which restricts the processors' market power, with opposite effects on the distribution of research benefits. Under perfect competition, the distribution of research benefits is not affected by the curvature of supply and demand.

## 6. Benefits from a pivotal supply shift

A pivotal shift in farm supply is given by a change in the slope parameter. This can be represented by defining the farm supply as $W = b + t\beta Q^{1/\rho}$, where initially $t = 1$, and after the shift, $0 < t < 1$. The new competitive equilibrium is given by

$$W_1^c = b + t\beta(Q_1^c)^{1/\sigma}; \quad P_1^c = a - \alpha(Q_1^c)^{1/\sigma};$$
$$Q_1^c = \left[\frac{\alpha+\beta}{\alpha+t\beta}\right]^{\sigma}.$$

Total economic surplus increases, as a result of the pivotal shift, by an amount equal to

$$\Delta SB^c = \frac{\alpha+\beta}{1+\sigma}\left[\left(\frac{\alpha+\beta}{\alpha+t\beta}\right)^{\sigma} - 1\right] > 0.$$

The benefits to consumers and farmers are:

$$\Delta CS^c = \frac{\alpha}{1+\sigma}\left[t\left(\frac{\alpha+\beta}{\alpha+t\beta}\right)^{1+\sigma} - 1\right] > 0,$$

$$\Delta PS^c = \frac{\beta}{1+\sigma}\left[t\left(\frac{\alpha+\beta}{\alpha+t\beta}\right)^{1+\sigma} - 1\right].$$

Farmers do not necessarily gain from a pivotal supply shift. Farmers are more likely to gain from a pivotal supply shift if they have a bigger share of the final product value and if supply is inelastic relative to demand. As in the case of a parallel shift, competitive processors do not benefit from a pivotal supply shift.

The equilibrium under imperfect competition with a pivotal supply shift is

$$W_1^m = b + t\beta(Q_1^m)^{1/\sigma}; \quad P_1^m = a - \alpha(Q_1^m)^{1/\sigma};$$
$$Q_1^m = \left[\frac{\alpha+\beta}{\Omega_3}\right]^{\sigma},$$

where $\Omega_3 = 1 + \xi/\sigma)\alpha + (1 + \theta/\sigma)t\beta$. The induced change in the deadweight loss from imperfect competition is $\Delta DWL = \Delta SB^c - \Delta SB^m$, where $\Delta SB^m = \Delta\Pi^m + \Delta PS^m + \Delta CS^m$. The elements of this change are defined below:

$$\Delta\Pi^m = \Pi_1^m - \Pi_0^m$$
$$= \left[\alpha+\beta-(\alpha+t\beta)(Q_1^m)^{1/\sigma}\right]Q_1^m - (\alpha+\beta) \times [1-(Q_0^m)^{1/\sigma}]Q_0^m;$$

and

$$\Delta\Pi^m > 0 \quad \text{if } (\xi\alpha + t\theta\beta)\Omega_1^{1+\sigma} > (\xi\alpha+\theta\beta)\Omega_3^{1+\sigma}.$$

$$\Delta PS^m = \frac{\beta[\sigma(\alpha+\beta)]^{1+\sigma}}{1+\sigma}\left[\frac{t}{\Omega_3^{1+\sigma}} - \frac{1}{\Omega_1^{1+\sigma}}\right] > 0$$

if $t\Omega_1^{1+\sigma} > \Omega_3^{1+\sigma}$.

$$\Delta CS^m = \frac{\alpha[\sigma(\alpha+\beta)]^{1+\sigma}}{1+\sigma}\left[\frac{1}{\Omega_3^{1+\sigma}} - \frac{1}{\Omega_1^{1+\sigma}}\right] > 0.$$

The total benefit and its distribution under imperfect competition depend on six parameters: $\theta$, $\xi$, $\phi$, $\sigma$, $s$, and $t$. As in the linear model, the total benefit from a pivotal supply shift in the generalized linear model can be greater under imperfect competition than under perfect competition. Extensive simulation results indicate that a deadweight gain is more likely to occur when demand is inelastic relative to supply and when processors' oligopsony power is greater than their oligopoly power. The intuition behind these results is first, that inelastic demand implies a relatively large decrease in the consumer price and, second, that a pivotal supply shift increases the elasticity of supply and, hence, reduces processors' opportunities to exercise oligopsony power, and this effect is more important the greater is the degree of oligopsony power.

Consumers always benefit from a pivotal supply shift. Processors always benefit when they have oligopoly power alone. For oligopsony power alone, processors benefit from the shift only if $ts(1+\theta/\sigma)[t^{-\sigma/(1+\sigma)}-1] > \phi[1-t^{1/(1+\sigma)}]$. That is, processors benefit more when their degree of oligopsony power is high, when the farm product share is high, and when supply is inelastic relative to demand. Producers lose from the pivotal shift when supply is elastic relative to demand and when supply is more convex. An increase in $\sigma$ will reduce processors' oligopsony and oligopoly power, therefore resulting in a smaller research benefit from the pivotal supply shift to processors, but a greater benefit to producers.

## 7. Importance of functional forms: simulation results for four cases

Although the qualitative results are similar, the quantitative differences may be important among different models nested within the generalized linear model. In addition, there may also be important differences relative to the commonly used constant-elasticity model. To evaluate this possibility, we compared total research benefits and the distribution of benefits from a parallel or pivotal supply shift given a set of values for supply and demand elasticities and market power parameters, using four alternative specific models: quadratic, linear, square-root, and constant-elasticity. All four models are special cases of the general form in equations (7) and (8). The first three models are special cases of the general linear model studied in the preceding section. The constant-elasticity model is not a special case of the generalized linear model, and results for the constant elasticity model are based on derivations given in the Appendix A.

### 7.1. Parallel supply shift

Table 1 reports the effects of processor market power on the size and distribution of benefits from a 0.01 per unit (i.e., 1% vertically) parallel supply shift with the four alternative functional forms. For these comparisons we always hold the underlying farm-level supply and retail demand functions constant, as defined by the quantity and price and the elasticities of supply and demand at the competitive equilibrium, to explore the effects of different forms of competition on the benefits from research. In each case, the initial competitive farm share is one half (i.e., $c = 0.5$). With this parameterization, when we change an assumption about the form of competition, we define new equilibrium values for the without-research price and quantity ($P_0^{\mathrm{m}}$, $Q_0^{\mathrm{m}}$) and, thus, for every functional form except the double-log, the without-research elasticities of supply and demand change as the form of competition changes. Hence, some differences in effects of research across models, for a given form of imperfect competition, are attributable to the fact that the elasticities differ across models in the without-research equilibrium. The alternative to this approach is to hold the supply and demand elasticities constant at the without-research equilibrium across forms of competition. This approach will cause the without-research supply and demand curves to shift as the form of competition changes. We report some results based on this simulation strategy in Table 3.

Under perfect competition, the total benefits from a parallel supply shift, and the distribution of the benefits, are essentially identical across the four functional forms, regardless of the elasticities of supply and demand. Under market power, however, total research benefits and its distribution, vary across functional forms. The elasticity of demand plays an important role.

In the top half of Table 1, retail demand is elastic and farm supply is inelastic ($\epsilon_{\mathrm{f}} = 0.7$, $\eta_{\mathrm{r}} = 1.3$). Under imperfect competition, total benefits from a parallel supply shift are affected only slightly by the choice of functional forms. In particular, under Cournot duopsony ($\theta = 0.5$), total benefits show a standard deviation among functional forms less than 1 percent of the mean value for all four functional forms. Under Cournot duopoly ($\xi = 0.5$), total benefits vary a little more, with a standard deviation of about 3% of the mean value.[6] Under both duopsony and duopoly ($\theta = 0.5$, $\xi = 0.5$), the standard deviation of total benefits across functional forms is about 2% of the mean value, less than under duopoly alone. In contrast, the distribution of benefits varies quite markedly across functional forms. Under duopsony, processors' share of benefits varies from 26 to 42%, producers' share varies from 28 to 35%, and consumers' share varies from 30 to 44%. Under duopoly, the variation is even greater: $S_{\mathrm{p}}$ varies from 7 to 44%, $S_{\mathrm{f}}$ varies from 27 to 35%, and $S_{\mathrm{c}}$ varies from 29 to 59%. Combining duopsony and duopoly power results in $S_{\mathrm{p}}$ varying from 25 to 60%, $S_{\mathrm{f}}$ ranging from 19 to 28%, and $S_{\mathrm{c}}$ varying from 21 to 53%.

Some systematic patterns emerge across functional forms, regardless of the form of market power. The processors' share of benefits falls progressively as we go from the most concave (quadratic) form of demand to the increasingly convex linear, square-root, and double-log models. The implications of this curvature are that the demand slope becomes steeper with the more convex functions as quantity is reduced by market power, and a given research-induced quantity increase has a greater effect on the consumer price, accordingly, for the more convex functions. Hence, the consumer share of the total benefits increases, with increasing convexity of demand, in conjunction with the decreasing processors' share. Unlike the ranking of functional forms in terms of shares of benefits going to processors and consumers, the ranking of the functional forms in terms of either total benefits or

[6] The effects of oligopoly power are greater than the effects of oligopsony power, ceteris paribus, because the impact of oligopsony power is weighted by the fractional farm share, $c = 0.5$ in our simulations. Thus, in general, the importance of oligopsony power in the analysis of research benefits is tied directly to the relative importance of the farm product in the costs of producing the retail product.

Table 1
Effects of processor market power on the size and distribution of research benefits from a 1% parallel supply shift[a]

| Market situation | Parameters | Distribution of benefits (%) | | | Total benefits | Deadweight loss (%) |
|---|---|---|---|---|---|---|
| | | Processors | Farmers | Consumers | | |
| ($\epsilon_f = 0.7$, $\eta_r = 1.3$) | | | | | | |
| *Competition* | $\theta = 0/\xi = 0$ | | | | | |
| Quadratic | | 0.0 | 48.1 | 51.9 | 10034 | 0.0 |
| Linear | | 0.0 | 48.1 | 51.9 | 10034 | 0.0 |
| Square-root | | 0.0 | 48.1 | 51.9 | 10034 | 0.0 |
| DL | | 0.0 | 48.3 | 51.7 | 10034 | 0.0 |
| *Oligopsony* | $\theta = 0.5/\xi = 0$ | | | | | |
| Quadratic | | 41.9 | 28.0 | 30.1 | 9656 | 4.5 |
| Linear | | 32.4 | 32.5 | 35.1 | 9614 | 3.8 |
| Square-root | | 26.5 | 35.4 | 38.1 | 9583 | 3.2 |
| DL | | 25.9 | 30.2 | 43.9 | 9711 | 4.2 |
| *Oligopoly* | $\theta = 0/\xi = 0.5$ | | | | | |
| Quadratic | | 43.7 | 27.1 | 29.2 | 9608 | 5.0 |
| Linear | | 34.1 | 31.7 | 34.2 | 10280 | 4.2 |
| Square-root | | 28.0 | 34.7 | 37.3 | 9532 | 3.6 |
| DL | | 6.8 | 34.0 | 59.2 | 9668 | −2.5 |
| *Oligopsony/Oligopoly* | $\theta = 0.5/\xi = 0.5$ | | | | | |
| Quadratic | | 60.0 | 19.3 | 20.7 | 8919 | 11.6 |
| Linear | | 50.0 | 24.1 | 25.9 | 9411 | 11.1 |
| Square-root | | 42.9 | 27.5 | 29.6 | 8869 | 10.4 |
| DL | | 25.2 | 22.3 | 52.5 | 8990 | 6.2 |
| ($\epsilon_f = 1.3$, $\eta_r = 0.7$) | | | | | | |
| *Competition* | $\theta = 0/\xi=0$ | | | | | |
| Quadratic | | 0.0 | 21.2 | 78.8 | 10028 | 0.0 |
| Linear | | 0.0 | 21.2 | 78.8 | 10028 | 0.0 |
| Square-root | | 0.0 | 21.2 | 78.8 | 10028 | 0.0 |
| DL | | 0.0 | 21.3 | 78.7 | 10028 | 0.0 |
| *Oligopsony* | $\theta = 0.5/\xi = 0$ | | | | | |
| Quadratic | | 24.1 | 16.1 | 59.8 | 9935 | 1.2 |
| Linear | | 17.5 | 17.5 | 65.0 | 9909 | 0.9 |
| Square-root | | 13.6 | 18.3 | 68.1 | 9905 | 0.7 |
| DL | | 11.4 | 16.4 | 72.2 | 9954 | 1.2 |
| *Oligopoly* | $\theta = 0/\xi = 0.5$ | | | | | |
| Quadratic | | 54.2 | 9.7 | 36.1 | 9227 | 8.7 |
| Linear | | 44.1 | 11.9 | 44.0 | 11953 | 8.0 |
| Square-root | | 37.1 | 13.3 | 49.6 | 9152 | 7.2 |
| DL | | −24.8 | 9.0 | 115.8 | 9302 | −19.2 |
| *Oligopsony/Oligopoly* | $\theta =0.5/\xi = 0.5$ | | | | | |
| Quadratic | | 60.0 | 8.5 | 31.5 | 8913 | 11.6 |
| Linear | | 50.0 | 10.6 | 39.4 | 11253 | 11.1 |
| Square-root | | 42.9 | 12.1 | 45.0 | 8863 | 10.4 |
| DL | | −18.9 | 7.2 | 111.7 | 8985 | −12.2 |

[a] Notes: Total benefits in the table are defined as dollars of economic welfare change per million dollars of competitive industry gross revenue. The deadweight loss is measured as a percentage of the total benefits under perfect competition. The parallel supply shift is by 0.01 per unit, equal to 1% of the initial consumer price, and 2% of the initial farm price, given $c = 0.5$.

the farmers' share does depend on the form of competition. Lastly, the deadweight loss from market power tends to increase as a result of research, but less so for the models with more-convex demand functions and, in one case, with the double-log model and Cournot duopoly, the deadweight loss from oligopoly power actually decreased as a result of research.

In the lower half of Table 1 demand is inelastic and supply is elastic ($\epsilon_f = 1.3$, $\eta_r = 0.7$); the effects of functional form on research benefits are similar to those in the previous case, but more pronounced. The reasons are worth noting. First, the impact of market power is always determined jointly by the index of market power ($\theta$, $\xi$, or both) and the corresponding supply or demand elasticity. Hence, an inelastic demand combined with an elastic supply magnifies the importance of oligopoly power relative to oligopsony power, and the fractional farm share means that oligopoly power is always more important, ceteris paribus (see note 6). Total benefits under imperfect competition vary modestly across functional forms, with a standard deviation less than 1% of the mean value under duopsony, about 12% under duopoly, and about 11% under duopsony/duopoly.

The role of curvature of demand is more pronounced with an inelastic demand than in the previous case with an elastic demand. Processors lose from a parallel shift under duopoly in the constant-elasticity model, while in all three other models they necessarily gain from the shift, more so the less convex is the demand curve. Hence, under duopoly, in the constant-elasticity model, consumers capture more than 100% of the total benefits, and the consumers' share is greater than under competition since the reduction in consumer price is always greater under market power than under competition, while for all three other functional forms the consumers' share of the benefits is smaller than under competition. Again, in those cases where processors are made worse off by the supply shift (cases with oligopoly power and a double-log model), the deadweight losses from market power are reduced by research.

### 7.2. Pivotal supply shift

The simulations of the effects of market power on the size and distribution of research benefits from a 1% pivotal supply shift are summarized in Table 2. In this case, unlike the case of a parallel shift, the four alternative functional forms generate quite different research benefits, even under perfect competition. In the top half of Table 2 demand is elastic and supply is inelastic, and the standard deviation of total benefits is 24–25% of the mean value, for all four functional forms. In the quadratic and linear models, farmers may lose from a pivotal supply shift under both competition and market power, while farmers never lose in the constant-elasticity model or the square-root model. Processors and consumers always benefit from a pivotal shift, but their shares vary greatly across the four functional forms.

The bottom half of Table 2 depicts inelastic demand and elastic supply, and here the variations in total benefits and the distribution of benefits among the four functional forms are even more significant, as anticipated. The standard deviation of total benefits is 27% of the mean value across the four functional forms under perfect competition or duopsony, and 37% under duopoly or duopsony/duopoly. Processors may lose from a pivotal supply shift in either the linear model or the constant-elasticity model, while in the other two models they always gain under imperfect competition. Farmers always lose from a pivotal shift when demand is inelastic, but their losses vary greatly across the four functional forms and are a decreasing function of the degree of convexity in the underlying model. Consumers benefit from a pivotal shift, as usual, but their share varies a lot across the functional forms.

It is difficult to see clear patterns in the results for pivotal supply shifts compared with those for parallel shifts in Table 1. Market power, functional forms, elasticities, and the nature of the research-induced supply shift interact in complex ways. One result is clear, consumers always gain from research. Another clear result is that farmers always lose when supply pivots against an inelastic demand, regardless of the form of competition. Even when demand is elastic, farmers might lose from a pivotal research-induced supply shift under imperfect competition.

### 7.3. Potential approximation errors

We now turn attention to the question of the likely size of errors of approximation that would be made by arbitrarily, and incorrectly, assuming a particular form of competition, form of supply shift, or functional form of supply and demand or, perhaps worse, a combination of more than one of these errors. The challenge here is to define a meaningful set of com-

Table 2
Effects of processor market power on the size and distribution of research benefits from a 1% pivotal supply shift[a]

| Market situation | Parameters | Distribution of benefits (%) | | | Total benefits | Deadweight loss (%) |
|---|---|---|---|---|---|---|
| | | Processors | Farmers | Consumers | | |
| ($\epsilon_f = 0.7$, $\eta_r = 1.3$) | | | | | | |
| *Competition* | $\theta = 0/\xi = 0$ | | | | | |
| Quadratic | | 0.0 | −59.7 | 159.7 | 5034 | 0.0 |
| Linear | | 0.0 | −4.1 | −104.1 | 5867 | 0.0 |
| Square-root | | 0.0 | 22.1 | 77.9 | 3368 | 0.0 |
| DL | | 0.0 | 11.1 | 88.1 | 6701 | 0.0 |
| *Oligopsony* | $\theta = 0.5/\xi = 0$ | | | | | |
| Quadratic | | 42.6 | −35.0 | 57.4 | 5175 | 4.7 |
| Linear | | 10.2 | 10.2 | 79.6 | 5824 | −2.8 |
| Square-root | | 26.2 | 16.2 | 57.6 | 3211 | 3.1 |
| DL | | 6.7 | 7.9 | 85.4 | 6492 | 0.7 |
| *Oligopoly* | $\theta = 0/\xi = 0.5$ | | | | | |
| Quadratic | | 45.1 | −33.5 | 88.4 | 4479 | 5.4 |
| Linear | | 58.5 | −16.9 | 58.4 | 5766 | 11.0 |
| Square-root | | 27.8 | 15.9 | 56.3 | 3187 | 3.6 |
| DL | | 9.7 | 6.5 | 83.8 | 6461 | 1.7 |
| *Oligopsony/Oligopoly* | $\theta = 0.5/\xi = 0.5$ | | | | | |
| Quadratic | | 60.7 | −24.0 | 63.3 | 4475 | 12.0 |
| Linear | | 50.0 | −2.0 | 52.0 | 5629 | 11.1 |
| Square-root | | 42.6 | 12.6 | 44.8 | 2965 | 10.3 |
| DL | | 13.4 | 4.6 | 82.0 | 6012 | 7.1 |
| ($\epsilon_f = 1.3$, $\eta_r = 0.7$) | | | | | | |
| *Competition* | $\theta = 0/\xi = 0$ | | | | | |
| Quadratic | | 0.0 | −140.6 | 140.6 | 5028 | 0.0 |
| Linear | | 0.0 | −58.0 | 158.0 | 7250 | 0.0 |
| Square-root | | 0.0 | −18.6 | 118.6 | 3362 | 0.0 |
| DL | | 0.0 | −9.1 | 109.1 | 6694 | 0.0 |
| *Oligopsony* | $\theta = 0.5/\xi = 0$ | | | | | |
| Quadratic | | 24.6 | −107.9 | 183.3 | 5291 | 1.2 |
| Linear | | −33.5 | −33.5 | 167.0 | 7270 | −5.2 |
| Square-root | | 13.3 | −16.0 | 102.7 | 3319 | 0.7 |
| DL | | −5.5 | −7.9 | 113.4 | 6649 | −0.3 |
| *Oligopoly* | $\theta = 0/\xi = 0.5$ | | | | | |
| Quadratic | | 55.1 | −64.2 | 109.1 | 4047 | 9.1 |
| Linear | | 72.3 | −44.6 | 72.3 | 8103 | 19.5 |
| Square-root | | 37.0 | −11.7 | 74.7 | 3055 | 7.2 |
| DL | | −28.1 | −3.1 | 131.2 | 6214 | −11.8 |
| *Oligopsony/Oligopoly* | $\theta = 0.5/\xi = 0.5$ | | | | | |
| Quadratic | | 60.6 | −56.5 | 95.9 | 4469 | 11.9 |
| Linear | | 50.0 | −29.0 | 79.0 | 8386 | 11.1 |
| Square-root | | 42.3 | −10.5 | 68.2 | 2961 | 9.5 |
| DL | | −30.2 | −2.6 | 32.8 | 6055 | −15.7 |

[a] Notes: See notes to Table 1. The pivotal supply shift is defined by a proportion such that the amount of the shift is 0.01 per unit at the initial competitive quantity.

parisons with a manageable number of dimensions. Our strategy is to hold some elements constant by using as a case study the US meat-packing industry for which we have estimates of the elasticities of supply and demand and the market power indices, and to consider only two alternatives for each of the remaining elements (types of supply shifts and functional forms), so that a total of four cases are defined.

Our estimates for US meat packing are from Azzam and Pagoulatos (1990), and are as follows: $\eta_r = 0.527$, $\epsilon_f = 1.689$, $\theta = 0.178$, and $\xi = 0.223$. Thus, Azzam and Pagoulatos found modest oligopoly and oligopsony power in the industry (i.e., equivalent roughly to that achieved in a five-firm, homogeneous-product Cournot oligopoly/oligopsony). These market power estimates are rather consistent with results found in other studies for other industries, as Sexton and Lavoie (1999) note in their recent survey, so our simulations should give reasonably general approximations of the types of errors that might be made by erroneously assuming perfect competition.

The supply shifts are, as above, pivotal or parallel; and the functional forms are linear or constant elasticity, the most popular forms for models of research benefits. The results in Tables 1 and 2 show that the most striking differences are between the linear and constant elasticity forms, while the other special cases of the generalized linear model (the quadratic and square root models) are relatively similar to the linear model, so the linear and constant elasticity models should give reasonable coverage of the possibilities.

Using the estimates for the US meat-packing industry and assumptions about the 'true' functional forms of supply and demand and the form of the research-induced supply shift (one of four possible combinations), we can measure the 'true' benefits from a one-percent research-induced supply shift. Then, by changing one of the elements and recomputing the benefits, we can establish the size of the error in the estimated research benefits resulting from the incorrect model specification.

However, in this set of experiments, unlike those reported in Tables 1 and 2, we do not hold the underlying supply and demand curves constant across forms of competition for a given functional form. Rather, as happens in practice, we take the market equilibrium as given (i.e., $Q = 1$, $P = 1$), observe elasticities at that equilibrium, and then make assumptions about (or obtain estimates of) the functional forms of demand and supply, form of the supply shift, and nature of competition. For a given set of elasticities, the different forms of competition will imply different parameter values for the underlying supply and demand curves. In other words, one of the implications of an error in an assumption about the form of competition is errors in the implied parameters of the underlying supply and demand functions, given elasticity values.

In Table 3, we consider in turn, the errors in the estimate of total research benefits and the distribution of benefits arising from errors in the assumptions about the functional form of supply and demand, the form of the research-induced supply shift, and the form of competition, individually and in various combinations. These comparisons are made twice, first, assuming the 'true' functional forms are linear and the supply shift is parallel, and second, assuming the 'true' functional forms are constant elasticity and the supply shift is pivotal. The comparisons for total benefits are in terms of errors in the estimate of the total welfare change, $\Delta$SB, expressed as a percentage of the 'true' change. For the shares of benefits the number reported is the difference between the estimated share, $S_i^1$, and true share, $S_i^0$ of total benefits, $S_i^1 - S_i^0$. Thus, for example a negative value in Table 3 means that the error resulted in underestimation of the share.

The upper half of Table 3 refers to the case where the 'true' scenario is a parallel shift of a linear supply function with $\epsilon_f = 1.689$, against a linear demand function with $\eta_r = 0.527$ (where the elasticities are measured at the without-research imperfectly competitive equilibrium), with $\theta = 0.178$ and $\xi = 0.223$. The 'true' distribution of social benefits is shown in the first line: $S_p = 30.7\%$, $S_f = 2.8\%$, and $S_c = 66.6\%$. The next seven lines report the percentage errors in the estimate of total benefits, and the errors in the estimated distribution of benefits, resulting from various specification errors.

Line (1) reports the errors that result from assuming the wrong functional form. This mistake results in a fairly small (16.2%) error in the estimate of total benefits, but substantial errors in the distribution of benefits. Specifically, the true processor benefit is 30.7% of total social benefits but the processor share is estimated, erroneously, to be –22.1% (i.e., an error of –22.1 –30.7 = –52.8% of social benefits) – a loss rather than a gain. The true consumer share is 66.6%, but this gain is over-estimated (by 50.6 percentage points) to be 117.2% of the net social benefit.

Line (2) refers to an error in the assumed form of the shift. Mistaking the form of the shift leads to understating the total benefits by 39% (as happens in a

Table 3
Errors in levels and distribution of research benefits from incorrect model specifications. The case of US meat packing ($c = 0.43$, $\epsilon_f = 1.689$, $\eta_r = 0.527$, $\theta = 0.178$, $\xi = 0.223$)[a]

| | % Error in $\Delta$SB | Errors in distribution of benefits | | |
|---|---|---|---|---|
| | | $S_p$ | $S_f$ | $S_c$ |
| True model is linear, parallel shift, and imperfect competition | | (30.7) | (2.8) | (66.6) |
| (1) If assume double-log functional forms of supply and demand (ff) | 16.2 | −52.8[b] | 2.1 | 50.6 |
| (2) If assume a pivotal supply shift (sh) | −39.4 | 4.2 | −67.8[b] | 63.5 |
| (3) If assume perfect competition (com) | −15.3 | −30.7 | 12.3 | 18.3 |
| (4) Both ff and sh | −11.7 | −73.2[b] | −31.2[b] | 104.8 |
| (5) Both ff and com | −15.3 | −30.7 | 12.4 | 18.2 |
| (6) Both sh and com | −57.6 | −30.7 | −72.9[b] | 103.5 |
| (7) ff, sh, and com | −46.7 | −30.7 | −38.4[b] | 68.6 |
| True model is double-log, pivotal shift, and imperfect competition | | (−42.5) | (−28.9) | (171.4) |
| (1) If assume linear functional forms (ff) | −31.4 | 77.4[b] | −36.1 | −41.3 |
| (2) If assume a parallel supply shift (sh) | 31.6 | 20.4 | 33.8[b] | −54.2 |
| (3) If assume perfect competition (com) | 13.2 | 73.2[b] | 31.7[b] | −36.2 |
| (4) Both ff and sh | −39.7 | 42.5 | −6.7 | −36.2 |
| (5) Both ff and com | −52.0 | 42.5 | −41.2 | −1.3 |
| (6) Both sh and com | −4.1 | 42.5 | 44.1[b] | −86.6 |
| (7) ff, sh, and com | −4.1 | 42.5 | 44.0[b] | −86.5 |

[a] Notes: The numbers in parentheses are the values of $S_p$, $S_f$, and $S_c$ respectively, for the default model. The % error is defined as $(k-K)/K$, where $k$ is an approximation to the true value $K$. The errors in the distribution of benefits is defined as$S_i^1-S_i^0$, $I$ = p, f, c, where $S_i^1$ is an approximation to the true value$S_i^0$.
[b] The values indicate errors in the signs of the benefit shares.

competitive model), a modest overstatement of processor benefits, a major understatement of farmer benefits (indeed a benefit is falsely perceived as a loss, as would also happen with inelastic demand in a competitive setting), and a major overstatement of consumer benefits. Line (3) shows that mistakenly assuming a competitive market structure would result in a 15% underestimate of total benefits, a significant understatement of the benefits to processors, and a corresponding overstatement of the share of benefits to consumers and to farmers.[7] The remaining rows in the upper half of Table 3, lines (4)–(7), refer to combinations of errors. The effects of combining errors are not just the sum of the effects of individual errors, they interact significantly. In some cases, errors in model specification offset one another so that errors in the estimates of benefits are smaller than if only one error had been made.

The lower half of Table 3 refers to the case where the 'true' scenario is a pivotal shift of a constant-elasticity supply function, against a constant elasticity demand function, assuming the same values as before for the elasticities of supply and demand and the market power parameters. Assuming the wrong functional form (line (1)) results in a 31% understatement of total benefits, and similarly large errors in the estimates of the shares of benefits going to processors, farmers, and consumers, with a sign reversal on the processor benefits so that a loss is perceived as a benefit. Mistakenly assuming a parallel shift causes the analyst to overstate benefits by 32%, while also making important and predictable errors in the distribution of benefits. Erroneously assuming competition leads to understatement of total benefits by nearly 40%, with intuitive consequences for distribution, e.g., processors are believed to be unaffected when in fact they lose significantly. Mistakes made in combination again interact significantly in determining the size of the errors in the estimates of total benefits and its distribution, and multiple mistakes

[7] The result that erroneously assuming perfect competition causes the analyst to underestimate total benefits may seem counter-intuitive because, as earlier noted, benefits are less under imperfect competition in the linear model with parallel shifts due to increases in the deadweight loss from market power. The result occurs because the analyst understates the size of the market when he/she incorrectly infers that the observed equilibrium is competitive and, thus, understates the potential for research to generate benefits.

may result in offsetting errors in the estimation of benefits.

## 8. Conclusions

Several studies have reported on the relationship between measures of total research benefits and their distribution among processors, farmers, and consumers, and modeling choices concerning the nature of the research-induced supply shift under a maintained hypothesis of perfect competition. Similar results, however, might not hold under imperfect competition, and only limited results are available on the implications of the combination of different assumptions about the form of competition and other modeling choices for the resulting estimates of research benefits. We would like to know, in particular, how commonly used functional forms differ in terms of the magnitude and distribution of benefits from a particular research-induced supply shift, and the magnitude of error from using an incorrect functional form in a market characterized by processor market power either in buying the raw farm product or selling at retail, or both.

We have developed analytical results for a generalized model and numerical simulation results for the linear, quadratic, and square-root cases of this model, as well for the constant elasticity model, for pivotal and parallel research-induced supply shifts under a range of forms of competition. When the research-induced supply shift is parallel, the different functional forms yield identical measures of both total benefits and the distribution of benefits under perfect competition. Under imperfect competition, the different forms generate rather consistent results for total benefits. However, they result in significant differences in measures of the distribution of benefits, with the errors being larger, the less elastic is demand and the higher is the degree of market power. When the research-induced supply shift is pivotal, the choice of functional form matters significantly in measures of both total benefits and distribution of benefits, even under competition. The importance of functional form is magnified by the presence of market power in the case of a pivotal shift.

An illustrative example, based on elasticity estimates for the US meat-packing industry, was used to explore the potential quantitative importance of errors in assumptions about the functional forms for supply and demand, the form of the research-induced supply shift, the form of competition, or more than one of these errors, in a market setting characterized by a modest degree of both oligopoly and oligopsony power. It is well known that in a competitive market setting, the assumed form of the research-induced supply shift matters for both total research benefits, and the distribution of benefits; and this is also true in an imperfectly competitive setting. Thus, an error in this dimension always matters. However, unlike in the competitive setting, an error in the assumed functional form for supply and demand also matters under imperfect competition. Even with the moderate degree of market power in our example, an erroneous assumption of perfect competition led to important errors in the magnitude and particularly in the distribution of research benefits. Thus, getting the degree of competition correct matters not only in its own right but also in terms of serious potential errors from other specification mistakes. In general, there are significant interactions among the different potential specification errors.

This work has implications for research policy, in particular for the financing of research programs, and as well as for research evaluation. In relation to policy, the results here extend the work of Huang and Sexton (1996) and Alston et al. (1997) as to the effects of market power on the distribution of research benefits. The previous work showed that when the processing sector possesses oligopoly or oligopsony power, or both, it can capture a large share of research benefits. The present study affirms this result, under more general conditions, but also demonstrates that estimates of the distribution of benefits under imperfect competition are very sensitive to the assumptions made concerning the nature of the supply shift and the functional forms of supply and demand. Funding mechanisms that elicit support for agricultural research directly from the processing sector might be appropriate in industries where processor market power is thought to be important.

In relation to research evaluation, this work has shown the importance of assumptions about the functional forms for supply and demand, and the nature of the research-induced supply shift, in interaction with the form of competition, for measures of research benefits. Our view, shared by others in this field, is that data problems will generally preclude researchers from reaching definitive conclusions about either the functional forms of supply and demand or the form of the research-induced shift. In light of this limitation, it is especially important that researchers evaluate the structural conditions in the markets being modeled and either investigate empirically the competitive behavior in the market, or evaluate the importance of assumptions about competition by analyzing the sensitivity of results to alternative forms of competition. The conjectural variations oligopoly/oligopsony model studied here is a convenient vehicle to conduct such an investigation.

## Appendix A. Returns to research in a constant elasticity supply and demand model

As in the models presented in the text, prices and quantities at the competitive equilibrium without a supply shift are normalized by choosing units so that retail price and quantity are$P_0^c = 1$, $Q_0^c = 1$, and the farm product price is $W_0^c = 1 - c = s$. The retail market model is defined as

$$P = Q^{-1/\eta} \quad \text{retail demand},$$

$$P = tQ^{1/\epsilon} - z \quad \text{retail supply},$$

where $z = 0$ in the initial setting, and $z > 0$ represents a research-induced parallel shift of the retail supply function, and $t = 1$ in the initial setting, while $0 < t < 1$ represents a pivotal shift. $\eta_r > 0$ is the absolute value of the constant retail demand elasticity and, in the initial setting ($t = 1$), $\epsilon_r > 0$ is the constant retail supply elasticity.[8] Under the assumption of fixed proportions between the farm and processed product quantities, the farm supply is then[9]

$$W = tQ^{1/\epsilon} - z - c$$

The farm product supply elasticity at the initial competitive equilibrium is then

$$\epsilon_f = s\epsilon_r$$

### A.1. Pivotal supply shift

After a research-induced pivotal supply shift ($0 < t < 1$), the new competitive equilibrium is given by:

$$P_1^c = (Q_1^c)^{-1/\eta}; \quad W_1^c = P_1^c - C \quad \text{and}\, Q_1^c \cdot t^{-\epsilon\eta/(\epsilon+\eta)}.$$

The welfare effects are given by integrating the underlying functions. One feature of this functional form is that different expressions are derived for the special case where demand is unit elastic ($\eta = 1$). Here we do only report the expressions for $\eta \neq 1$; see Zhang (1997) for details.

As is well known, under perfect competition, producers benefit from a pivotal supply shift when demand is elastic and lose when demand is inelastic because, in the latter case, revenue falls faster than costs do when supply pivots down:

$$\Delta \mathrm{PS}^c = \frac{1}{1+\epsilon}[t^{\epsilon(1-\eta)/(\epsilon+\eta)} - 1].$$

However, consumers always benefit from a pivotal supply shift:

$$\Delta \mathrm{CS}^c = \frac{1}{\eta - 1}[t^{\epsilon(1-\eta)/(\epsilon+\eta)} - 1].$$

Total economic surplus increases by an amount equal to

$$\Delta \mathrm{SB}^c = \Delta \mathrm{PS}^c + \Delta \mathrm{CS}^c = \frac{\epsilon+\eta}{(1+\epsilon)(\eta-1)}[t^{\epsilon(1-\eta)/(\epsilon+\eta)} - 1].$$

These benefits are divided between producers and consumers as follows:

$$S_f^c = \frac{\eta - 1}{\epsilon+\eta}, \quad S_c^c = \frac{\epsilon+1}{\epsilon+\eta}.$$

Once again, defining the market-clearing conditions in terms of the oligopsony and oligopoly parameters, $\xi$ and $\theta$, the imperfectly competitive equilibrium with-

[8] A constant-elasticity retail supply function is defined instead of a constant-elasticity farm supply since it is much easier to derive the analytical results by starting with retail supply. Under the assumption of fixed proportions, using retail supply will not affect the results.

[9] One implication of this structure is that the supply function at retail passes through the origin, and the farm-level supply function intersects the price axis at a negative value. To avoid these problems would require displacing the retail supply function away from the origin, as in the generalized linear model in the text, whereupon it would no longer be a function with a constant elasticity.

out a supply shift is characterized by

$$P_0^{\mathrm{m}} = (Q_0^{\mathrm{m}})^{-1/\eta}; \quad W_0^{\mathrm{m}} = (Q_0^{\mathrm{m}})^{1/\epsilon} - c;$$
$$\text{and } Q_0^{\mathrm{m}} = \Phi^{\epsilon\eta/(\epsilon+\eta)}.$$

where $\Phi = (1-\xi/\eta)/(1+\theta/\epsilon)<1$. $Q_0^{\mathrm{m}}$ decreases with an increase in either $\theta$ or $\xi$, but the effect of oligopsony power on prices and quantities is determined jointly by $\theta$ and $\epsilon$ while the effect of oligopoly power is determined jointly by $\xi$ and $\eta$.[10] The deadweight loss from imperfect competition increases with an increase in either $\xi$ or $\theta$, as can be seen in:

$$\mathrm{DWL}_0^{\mathrm{m}} = \frac{1+\epsilon\Phi^{\eta(1+\epsilon)/(\epsilon+\eta)}}{1+\epsilon} + \frac{\eta\Phi^{\epsilon(\eta-1)/(\epsilon+\eta)} - 1}{1-\eta}.$$

The new equilibrium under imperfect competition after a pivotal supply shift is

$$P_1^{\mathrm{m}} = (Q_1^{\mathrm{m}})^{-1/\eta}; \quad W_1^{\mathrm{m}} = t(Q_1^{\mathrm{m}})^{1/\epsilon} - c;$$

and

$$Q_1^{\mathrm{m}} = (\Phi/t)^{\epsilon\eta/(\epsilon+\eta)} = Q_0^{\mathrm{m}} t^{-\epsilon\eta/(\epsilon+\eta)}.$$

The output expansion under imperfect competition relative to that under competition is $\Delta Q^{\mathrm{m}}/\Delta Q^{\mathrm{c}} = \Phi^{\epsilon\eta/(\epsilon+\eta)}<1$, i.e., the research-induced expansion in output is always less under imperfect competition than under competition. However, the reduction in the consumer price is always greater under market power, i.e., $\Delta P^{\mathrm{m}}/\Delta P^{\mathrm{c}} = \Phi^{-\epsilon/(\epsilon+\eta)} > 1$ The reason is that the constant-elasticity demand is convex, and a given output increase results in a greater price reduction at the smaller quantities associated with market power compared with competition.

The deadweight loss from imperfect competition after the pivotal supply shift, is

$$\mathrm{DWL}_1^{\mathrm{m}} = t^{\epsilon(1-\eta)/(\epsilon+\eta)} \mathrm{DWL}_0^{\mathrm{m}}.$$

Therefore, as a result of a pivotal research-induced supply shift, the deadweight loss from imperfect competition increases if demand is elastic ($\eta > 1$), is unaffected if demand is unit elastic ($\eta = 1$), and decreases if demand is inelastic ($\eta < 1$), given $\eta > \xi > 0$. Hence, research benefits are greater under oligopoly/oligopsony than under competition when demand is inelastic and the supply shift is pivotal.

The total research benefit under imperfect competition is given by

$$\begin{aligned} \Delta\mathrm{SB}^{\mathrm{m}} &= \Delta\mathrm{SB}^{\mathrm{c}} - \Delta\mathrm{DWL} \\ &= \Delta\mathrm{SB}^{\mathrm{c}} \frac{\Phi^{\epsilon\eta/(\epsilon+\eta)}}{\epsilon+\eta} [\eta(1+\epsilon)\Phi^{-\epsilon/(\epsilon+\eta)} \\ &\quad + \epsilon(1-\eta)\Phi^{\eta/(\epsilon+\eta)}] > 0. \end{aligned}$$

The benefit to consumers from a pivotal supply shift under imperfect competition is given by

$$\Delta\mathrm{CS}^{\mathrm{m}} = (\Delta\mathrm{CS}^{\mathrm{c}})\Phi^{\epsilon(\eta-1)/(\epsilon+\eta)} > 0.$$

Consumers always benefit from a pivotal supply shift in the constant-elasticity model, and they benefit more from research under imperfect competition than under competition when demand is inelastic. The benefit to producers from a pivotal supply shift under imperfect competition is given by

$$\Delta\mathrm{PS}^{\mathrm{m}} = (\Delta\mathrm{PS}^{\mathrm{c}})\Phi^{\eta(1+\epsilon)/(\epsilon+\eta)}.$$

It can be seen that $\Delta\mathrm{PS}^{\mathrm{c}} > \Delta\mathrm{PS}^{\mathrm{m}} > 0$ if $\eta > 1$, $\Delta\mathrm{PS}^{\mathrm{c}} = \Delta\mathrm{PS}^{\mathrm{m}} = 0$ if $\eta = 1$, and $0 > \Delta\mathrm{PS}^{\mathrm{c}} > \Delta\mathrm{PS}^{\mathrm{m}}$ if $0 < \xi < \eta < 1$. Hence, in the constant-elasticity model with a pivotal shift, farmers always gain less or lose more under market power than under competition. Finally, the change in processors' profit from a pivotal supply shift is given by

$$\Delta\Pi^{\mathrm{m}} = \frac{\eta\theta + \epsilon\xi}{\eta(\epsilon+\theta)} \Phi^{\epsilon(\eta-1)/(\epsilon+\eta)} [t^{\epsilon(1-\eta)/(\epsilon+\eta)} - 1].$$

When demand is inelastic, processors necessarily lose from the pivotal supply shift. When demand is unit elastic, a pivotal shift does not affect processors, and when demand is elastic, processors benefit from the shift.

Processor market power results in smaller research benefits to society, consumers, producers, and greater benefits to processors than under competition when demand is elastic, has opposite effects on each group when demand is inelastic, or no effect on total welfare and its distribution when demand is unit elastic. Table A.1 summarizes the results.

[10] Note that the necessary condition for the existence of the imperfectly competitive equilibrium in the constant-elasticity model is that $\eta > \xi$, i.e., the absolute value of the retail demand elasticity needs to be greater than the value of processors' oligopoly power parameter. This condition is not required for the existence of imperfectly competitive equilibrium in the generalized linear model.

Table A.1
Effects of market power on size and distribution of benefits from a pivotal supply shift in a constant elasticity model

| Welfare effect of research | Demand elasticity | | |
|---|---|---|---|
| | Elastic ($\eta > 1$) | Unit elastic ($\eta = 1$) | Inelastic ($0 < \xi < \eta < 1$) |
| Deadweight loss from market power ($\Delta$DWL) | $\Delta\text{DWL} > 0$ | $\Delta\text{DWL} = 0$ | $\Delta\text{DWL} < 0$ |
| Total social benefits ($\Delta$SB) | $\Delta\text{SB}^c > \Delta\text{SB}^m > 0$ | $\Delta\text{SB}^c = \Delta\text{SB}^m > 0$ | $0 < \Delta\text{SB}^c < \text{SB}^m$ |
| Consumer benefits ($\Delta$CS) | $\Delta\text{CS}^c > \Delta\text{CS}^m > 0$ | $\Delta\text{CS}^c = \Delta\text{CS}^m > 0$ | $0 < \Delta\text{CS}^c < \Delta\text{CS}^m$ |
| Producer benefits ($\Delta$PS) | $\Delta\text{PS}^c > \Delta\text{PS}^m > 0$ | $\Delta\text{PS}^c = \Delta\text{PS}^m = 0$ | $\Delta\text{PS}^m < \Delta\text{PS}^c < 0$ |
| Processor benefits ($\Delta\Pi$) | $\Delta\Pi^m > \Delta\Pi^c = 0$ | $\Delta\Pi^m = \Delta\Pi^c = 0$ | $\Delta\Pi^m < \Delta\Pi^c = 0$ |

The shares of total benefits going to processors, producers, and consumers under imperfect competition are:

$$S_p^m = \frac{(1+\epsilon)(1-\eta)(\Phi-1)}{\eta(1+\epsilon)+\epsilon(1-\eta)\Phi};$$

$$S_f^m = \frac{\eta-1}{\epsilon(1-\eta)+\eta(1+\epsilon)\Phi^{-1}};$$

$$S_c^m = \frac{1+\epsilon}{(1+\epsilon)\eta+\epsilon(1-\eta)\Phi}.$$

### A.2. Parallel supply shift

In the constant-elasticity model, a parallel supply shift down by $z$ per unit ($z > 0, t = 1$) changes the retail supply from $S_0$: $P = (Q^{1/\varepsilon})$ to $S_1$: $P = (Q^{1/\varepsilon}) - z$. A parallel supply shift makes the retail supply more inelastic for all $Q > 0$. The new competitive equilibrium is given by

$$P_1^c = (Q_1^c)^{-1/\eta}; \quad Q_1^c = (W_1^c + c + z)^\epsilon,$$

where $W_1^c$ is given by the implicit function

$$(W_1^c + c + z)^\epsilon = (W_1^c + c)^{-\eta}.$$

Total economic surplus increases, as a result of a parallel supply shift, by an amount equal to

$$\Delta\text{SB}^c = \Delta\text{PS}^c + \Delta\text{CS}^c > 0,$$

where

$$\Delta\text{PS}^c = \frac{(P_1^c)^{-\eta(1+\epsilon)/\epsilon}}{1+\epsilon} > 0,$$

$$\Delta\text{CS}^c = \frac{1-(P_1^c)^{1-\eta}}{1-\eta} > 0.$$

The new imperfectly competitive equilibrium is

$$P_1^m = (Q_1^m)^{-1/\eta}; \quad Q_1^m = (W_1^m + c + z)^\epsilon,$$

where $W_1^m$ is given by

$$(W_1^m + c + z)^{-\epsilon/\eta}\left(1 - \frac{\xi}{\eta}\right) = (W_1^m + c)(1 + \theta/\epsilon) + \theta z/\epsilon.$$

Consumers' benefit from a parallel supply shift under imperfect competition is

$$\Delta\text{CS}^m = \frac{(P_0^m)^{1-\eta} - (P_1^m)^{1-\eta}}{1-\eta} > 0.$$

Consumers always benefit from a parallel supply shift and consumers benefit more the lower is the degree of processor oligopsony power and the higher is the degree of processor oligopoly power.

Producers' benefit under imperfect competition is

$$\Delta\text{PS}^m = \frac{(W_1^m + c + z)^{1+\epsilon} - (W_0^m + c)^{1+\epsilon}}{1+\epsilon} > 0.$$

Producers always benefit from a parallel supply shift as long as the demand is not perfectly inelastic. Farmers' benefit from the parallel supply shift is gradually diminished by an increase in either $\theta$ or $\xi$.

As with a pivotal supply shift, processors always benefit from a parallel supply shift under imperfect competition when demand is elastic or unit elastic. When demand is inelastic but not very inelastic relative to supply, processors may lose from a parallel supply shift if their oligopoly power is greater than their oligopsony power. The deadweight loss from imperfect competition after the shift is

$$\text{DWL}_1^m = \frac{(W_1^c + c)^{1+\epsilon} - (W_1^m + c)^{1+\epsilon}}{1+\epsilon} + \frac{(P_1^m)^{1-\eta} - (P_1^c)^{1-\eta}}{1-\eta} - \Pi_1^m > 0.$$

The change in deadweight loss from imperfect competition is $\Delta DWL = \Delta SB^c - \Delta SB^m$. When processors have oligopsony power alone, a parallel supply shift increases DWL and the total research benefit is always smaller than under competition. For oligopoly power alone, there is always a deadweight gain. There are three subcases for this case of oligopoly power but no oligopsony power. When demand is inelastic, both farmers and processors are worse off from a parallel shift under processor oligopoly power than under competition (i.e., $\Delta PS^c > \Delta PS^m > 0$ and $0 = \Delta\Pi^c > \Delta\Pi^m$), but consumers are better off (i.e., $\Delta CS^m > \Delta CS^c > 0$). The positive effects of oligopoly power on consumer benefits exceed the negative effects on farmers and processors, and, therefore, total benefits increase with an increase in $\xi$. When demand is unit elastic, processors do not benefit from the parallel shift under oligopoly power alone (i.e., $\Delta\Pi^m = 0$), and the positive effects of oligopoly power on consumer benefits exceed its negative effects on farmer benefits; hence, a deadweight gain is assured. When demand is elastic, both processors and consumers, and society as a whole gain more from the research-induced supply shift under oligopoly power than under competition. When both oligopsony and oligopoly power exist, a deadweight gain is more likely to occur when demand is inelastic relative to supply and when $\xi > \theta$. Therefore, the total social benefit from a research-induced parallel supply shift may be greater under imperfect competition than under competition when demand is inelastic relative to supply and when oligopoly power is greater than oligopsony power. The total research benefit increases with an increase in $\xi$ and decreases with an increase in $\theta$.

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