REVISITING LONG-RUN INDUSTRY SUPPLY

Robert E. Martin
Centre College

INTRODUCTION

The "new economic geography" popularized by Paul Krugman (1980, 1991a, 1991b, 1994) emphasizes the importance of scale economies, transportation costs, and historical accidents in the geographic concentration of manufacturing and the distribution of world trade. Klettep [1996] demonstrates the importance of scale economies and innovation in product "life cycle" models where the presence, or absence, of scale economies influence the incentive to innovate. Scale economies are of two types: internal and external. Internal scale economies arise from conventional returns to scale in production. Returns to scale in production are "internal" to the firm since they result from the individual firm's choice of long-run output. They are driven by the technology available to the firm and determine the shape of the firm's cost curves. External economies, or diseconomies, can originate at either the industry level or from a combination of other industries. In any event, they are "external" to the firm.

The traditional discussion of external economies addresses the effects from the industry's output. Krugman notes there are three sources: (1) "... a pooled market for workers with industry-specific skills ..." (2) "... localized industries (that) can support the production of nontradable specialized inputs ..." and (3) "... informational spillovers (that) can give clustered firms a better production function than isolated producers" (1991b, 484-85). Vivid examples of the importance of these "informational spillovers" can be found in Saxenian's comparative study of the electronics industries in "Silicon Valley" California and "Route 128" in Massachusetts [1994] and in Milgrom and Roberts' [1990] analysis of the revolution taking place in manufacturing.

Unfortunately, scale economies, long-run industry supply, and the impact of market structure are not well integrated topics in economics. This is evidenced by the cryptic treatment these issues receive in graduate text books.1 The new economic geography, world trade patterns, and the product life cycle literatures illustrate the importance of reconsidering scale economies and long-run industry supply. A clear articulation of the difference between internal and external scale economies is also useful in explaining the determinants of average plant size and the impact of monopolization. The following model is a unified treatment of internal and external scale economies, entry/exit conditions, industry supply and the impact of plant property rights concentration.

SCALE ECONOMIES AND COST

Let the representative firm's output be \( x \) and let \( a \) be a vector of inputs of length \( k \). Given a strictly quasi-concave production function, cost minimization yields a total cost curve, say \( C^*(x, w) \), where \( w \) is a vector of input prices. Long run average cost is \( C^*(x, w)/x \). The long-run total cost function is derived assuming input prices remain constant as the representative firm changes its output. This is a reasonable assumption for the individual firm's output, but may not be reasonable for industry supply, \( M' \). The impact of \( M' \) on the firm's long-run cost may arise from industry based external scale economies.\(^1\)

Industry-based external scale economies may be either pecuniary or technological (Krugman, 1991b, 465). An example of pecuniary externalities is the effect of industry output on the supply prices of inputs. Circular causality between the concentration of output and the concentration of demand suggests that workers relocate where output is concentrated (Krugman, 1991b). If expansion of industry output induces labor migration, wage rates may decline as industry output expands. Technological spillovers can also be modeled through the effect of industry output on input prices. If informational spillovers rise as industry scale increases, input productivity may improve lowering price per unit of service flow from the input as industry output increases. External scale economies suggest a variety of reasons why input prices may vary with industry supply. Therefore,

\[
\begin{align*}
\omega &= w(M^k), \\
\delta w/\partial M^k &\neq 0 \text{ for some } i.
\end{align*}
\]

The distinction between pecuniary externalities and technological spillovers rests on the interpretation of \( \omega \): Let

\[
C(x, M) = C^*(x, w(M^k)),
\]

where \( C(x, M) \) is the reduced-form cost function. Therefore,

\[
C'_x = \Sigma i(M^k/\partial w_i/\partial M^k).
\]

The derivative of the reduced-form cost function with respect to the firm's output is \( C'_x(x, M) \), whereas equation (3) represents the derivative with respect to industry output. Note that \( C'_x(x, M) = C^*_x/\partial x \) and \( C'_x(x, M) = \partial C^*/\partial x \).

External scale economies are said to exist if \( C'_x(x, M) \) in equation (3) is negative. One might expect the effect of external scale economies on the reduced-form cost function to be characterized by diminishing marginal returns, which would suggest that \( C(x, M) \) is convex in \( M \). The absence of external scale economies implies \( C'_x(x, M) \) equals zero. External scale dis-economies occur when \( C'_x(x, M) \) is positive.

LONG-RUN INDUSTRY SUPPLY DEFINED

The long-run industry supply curve is the locus of price and industry output such that each firm is maximizing profit and the free entry/exit of firms has eliminated all economic profit so that the marginal firm/entrant is indifferent to exit/intrusion. Given homogeneous firms neither will there be intramarginal rents. It is important to note that the theory of long run competitive supply consists of two parts: a positive theory of the firm's output choice and a positive theory of the marginal firm’s entry/exit decision.

It is now possible to solve for the industry supply price (the inverse supply curve), the optimal output of the representative firm, and the number of firms. Let \( n \) be the number of firms in the industry. The number of firms in the industry, the output of the representative firm, and the long-run industry supply price, say \( p' \), are implicitly defined by

\[
\begin{align*}
\Pi &= p'x - C_n(x, M) = 0, \\
\Pi_n &= p' - C_n(x, M) = 0, \\
0 &= M - nx = 0,
\end{align*}
\]

where \( M \) is the exogenous variable that identifies the inverse supply function. The Jacobian determinant for the system in equation (4) is

\[
|J| = x^2C''_n(x, M) > 0,
\]

by profit maximization.

Mas-Colell, Whinston, and Green (1995, 334-41) prove that a competitive long-run equilibrium is inconsistent with decreasing returns to scale throughout, \( C'_w(x, M) > 0 \) for all \( x \). From equations (4a) and (4b), we have:

\[
C'_w(x, M) = C'_w(x, M) = C'_w(x, M) = 0.
\]

The conditions that implicitly define the long-run supply curve require marginal cost to equal average cost. Given decreasing returns to scale throughout, the only output at which marginal cost equals average cost is \( s = 0 \) for the representative firm. However, the condition in equation (0) is not defined for \( x = 0 \). Hence, equations (4a) and (4b) lead to a contradiction with decreasing returns to scale throughout. Increasing returns to scale throughout is the "natural monopoly" case, which is also inconsistent with pure competition. Consequently, competitive industry supply with \( n > 1 \) is consistent only with variable returns to scale in production. Further, variable returns to scale are not sufficient to insure \( n > 1 \). The size of the market must be such that there is "room" for more than one firm; that is, market quantity demanded must be greater than the representative firm's minimum efficient scale. The existence of an industry supply curve where \( n > 1 \) requires \( C'_w(x, M) > 0 \) and variable returns to scale.
Implicit differentiation of the system of equations in (4) with respect to $M$ reveals,

$$\frac{\partial p^*}{\partial M} = C_p'(x, M)/x.$$ \hfill (7)

after substitution from equation (5). Thus, the sign of the slope of the industry supply curve is the same as the sign of $C_p'(x, M)$. The supply price is increasing if $C_p'(x, M) > 0$, constant if $C_p'(x, M) = 0$, and decreasing if $C_p'(x, M) < 0$. Furthermore, note that $C_p'(x, M)/x$ is the derivative of the representative firm’s average cost schedule with respect to industry output. Increasing, constant and decreasing cost industries are defined according to the nature of external scale economies.

**EQUILIBRIUM: EXISTENCE AND STABILITY**

Let the industry inverse demand curve be $p^* = p(M)$, where $\frac{\partial p}{\partial M} = p'/M < 0$. If the equilibrium quantity is $M$, the system of equations that define industry equilibrium is

\begin{align*}
(8a) & \quad \Pi = px - C(x, M) = 0, \\
(8b) & \quad \Pi = p - C_p(x, M) = 0, \\
(8c) & \quad M - nx = 0, \\
(8d) & \quad p - p(M) = 0,
\end{align*}

where $p$ is the equilibrium price. The Jacobian determinant for this system is

$$|J| = x^3C_{xx}[p'(0M) - C'_x(x)]$$ \hfill (9)

$$= x^3C_{xx}[p'/3M - p'/\partial M].$$

The term in brackets is the difference between the slope of the inverse demand curve and the slope of the supply curve from equation (7). Assuming the equilibrium exists, the Jacobian in equation (9) does not vanish. If the market is stable, the Jacobian determinant is negative. If the market is unstable, the Jacobian determinant is positive. This result illustrates the relationship between existence and stability.

If the demand curve slopes downward and the supply curve has positive slope, or is horizontal, the market is stable and the Jacobian in equation (9) is negative. A problem may arise if the supply curve has negative slope. In this event, the market will be stable if and only if the absolute value of the slope of the inverse demand curve is less than the absolute value of the negatively sloped inverse supply curve [Russell and Wilkinson, 1979, 229]. Therefore, market stability implies,

\begin{align*}
(10a) & \quad p(nx) = C(nx, nx) = C_n'(x, nx)x < 0 \quad \text{as } C_n > 0, \\
(10b) & \quad p(nx) = C(nx, nx) = C_n'(x, nx)x < 0 \quad \text{as } C_n < 0.
\end{align*}

Let the competitive solutions to equation (8) be $x^*$, $n^*$, $M^*$, and $p^*$.

**MONOPOLY**

In this section I present an "experiment" that enables the direct comparison of the long run competitive model with the long-run monopoly model. Assume the $n^*$ independent perfect competitors in our model are acquired by a single agent. The only immediate change is the transfer of plant property rights from the $n^*$ agents to a single agent. The deployment of real assets has not yet changed. Since only the distribution of property rights has changed, all of the results obtained in the previous sections still hold. For example, if our "monopolist" chooses to be an absentee owner and allow all $n^*$ plant managers to operate independently, the results will be the same as in the previous sections. Alternatively, if the monopolist centralizes control; then, the multi-plant monopolist’s objective function is

$$\max_{n^*} \Pi = (p(nx)x - C(x, nx))n.$$

Our firm is both a monopolist and a monopolist in the input markets. By choosing both $n$ and $x$, the monopolist is also choosing $M$. Therefore, if industry output affects resource prices as described above, the monopolist is also setting resource prices by choosing $M$. Note, we have substituted $nx$ for $M$ in equation (10). The assumptions of perfect competition make it appropriate for the representative firm to ignore the impact of its output choice on industry output and average cost. Since the monopolist chooses $M$, it is inappropriate for the monopolist to ignore the shift in representative plant cost that occurs as a result of changing industry output. The first-order conditions can be rewritten as

\begin{align*}
(11a) & \quad p(nx) - C_n(x, nx)x = C_n'(x, nx)x - p(nx)xnx, \\
(11b) & \quad p(nx)x - C_n(x, nx)x = C_n'(x, nx)x - p(nx)xnx-nx^n.
\end{align*}

Let the optimal monopoly solutions be $x^*$ and $n^*$. The competitive market industry equilibrium stability condition in (9) requires the term in brackets on the right-hand side of both (11a) and (11b) to be positive if both the inverse demand curve and the inverse competitive industry supply curve are "well-behaved." Therefore, price is greater than marginal cost and profit per plant is positive in the monopoly solution. If the first-order conditions are satisfied, the problem reveals optimal plant output and the number of plants are chosen such that

$$C_n(x^*, n^*; x^*) = C(x^*, n^*; x^*).$$
Since equation (12) reveals that marginal cost equals average cost for each plant, the multiple plant monopolist will choose plant output and the number of plants such that all internal scale economies are fully exploited, just as under perfect competition. Furthermore, the first order conditions reveal that free entry will force our monopolist to choose the same plant output and number of plants as under perfect competition. From equation (11b), if the term on the right hand side is positive, then the monopolist's profit per plant is positive. Thus, if entry is free these positive profits will be competed away by new entrants. In order to prevent this entry, the monopolist will have to expand the number of plants to the point where the term in brackets on the right hand side of both equations (11a) and (11b) must be zero. Consequently, the monopolist's long-run price will equal marginal cost and profit per plant will be zero, just as in perfect competition. Concentration does not matter with free entry.

Given restricted entry and well-behaved demand and supply curves or an unstable market with a negatively sloped competitive supply curve, it is easy to show that $a^* < c^*$. Since equation (12) holds despite entry conditions, the difference between the monopolist and perfect competition is in the number of plants. Monopsonization will lead to fewer plants and a lower industry output, as expected. The competitive equilibrium stability condition in equation (9) insures that profit per plant is decreasing in $n$. Since profit per plant is positive under monopoly and zero under free entry, the number of plants operated by the monopolist is less than the number of plants in long-run competitive equilibrium.

In contrast, the stability conditions in equation (9) imply the terms on the right hand side of equations (11a) and (11b) are negative if the inverse supply curve is negatively sloped ($C_p < 0$). If the monopolized competitive industry is a stable decreasing cost industry and the relative stability conditions hold globally, the first order conditions in equations (11a) and (11b) reveal an interior maximum solution does not exist for the monopolist. The first order conditions yield a contradiction. The stability condition (when the supply curve is negatively sloped) requires average cost to fall faster than prices as the monopolist increases output. Therefore, profit per plant is monotonically in the number of plants. While the competitive market is stable, this stability implies no interior profit solution for the monopolist. Alternatively, if the industry is an unstable decreasing cost industry, the results are the same as when supply is well-behaved. Monopoly profit is positive.

If there are diminishing marginal returns to the external scale economies, then the competitive industry supply curve would be negatively sloped and convex in $M$. In this case, the market demand curve and the supply curve may intersect twice, as in Figure 1. The stable competitive industry solution occurs at $p^*, M^*$. However, the monopolist's profit is still increasing at $p^*, M^*$. If entry is free, the monopolist will continue to expand output to $p^*, M^*$, where output is higher and price is lower than the competitive solution. If entry is costly the monopolist will choose a price/output combination between $p^*, M^*$ and $p^*, M^*$. This unusual result occurs because the scale economies are, by definition, external to the individual competitive firm, whereas the monopolist internalizes the previously external scale economies. The monopolist exploits all available internal and external scale economies, which results in a higher output and a lower price for the monopolist.

POSSIBLE INTERPRETATIONS

The integrated model of long-run supply yields the following results. Transferring all plant property rights to one agent will not alter the competitive solution unless entry is restricted. Concentration does not matter when markets are contestable [Baumoel, Panzar, and Willig, 1982]. The monopoly agent chooses long-run plant output to exploit all internal scale economies, just as in perfect competition. Given restrictions on entry, the monopolist differs only in the number of plants in operation. The monopolist will operate fewer plants than the competitive industry. If the formerly competitive industry was a stable decreasing cost industry, an interior monopoly solution with non-negative profit does not exist. Significant external scale economies can result in no interior profit maximizing solution for the monopoly firm. Surprisingly, if there are diminishing marginal returns to the external scale economies, the output chosen by the monopolist may be greater than the output chosen by the competitive industry and the monopoly price may also be lower.

One may argue that the external economies model has growing implications for economic policy. Milgrom and Roberts claim that manufacturing is experiencing a "revolution" [1990, 511]. This historic change in manufacturing is the direct consequence of information technology. The integration of computer controlled manufacturing, distribution, and product design has a profound effect on minimum batch size,
product quality, and inventories [1990, 511-16]. Furthermore, this technology is
making the "border of the firm" increasingly ambiguous. In order to make manufac-
turing more agile and lower inventory costs, firms network their computers with both
suppliers and customers. The networking of computing systems represents the type of
information spillover that leads to external economies. As we have seen, external
economies can result in higher outputs at lower prices, even under monopoly. Fur-
thermore, the ambiguous border of the firm suggests that our traditional concepts of
concentration based on the number of firms may become obsolete.

High technology industries, particularly electronics, exhibit cost characteristics
that suggest they may be decreasing cost industries. Clearly, part of their historical
decline in both real and nominal supply price is attributable to rapid technical change.
However, Saxonian's [1994] electronics industry study strongly suggests there are
important informational spillovers in the industry. The unified scale economies model
in this paper implies that increased market concentration may be a Pareto superior
result in this case.

NOTES

The author is indebted to David Bradford, Bruce Johnson, and two anonymous referees for their
comments on an earlier version of this manuscript. All remaining errors are my own.

1. For example, Varian [1992, 236] states without qualification that "the industry supply function is
simply the sum of the individual firm supply functions." Despite the excellent treatment and cover-
age (for book weights at five pounds) of Max-Colell, Whinston, and Green's [1995] new text, they do
not consider long-run industry supply in the case where industry output influences input prices, nor
do they make a direct comparison between long-run competition and monopoly.

2. External scale economies from other industries can be modeled by including the industry outputs in
the firm's cost function.

3. One may wish to substitute for a from equation (9e) and reduce the system to two endogenous vari-
ables, p and n. The results will be the same for the shape of the long-run industry supply function as
the results one obtains from the three equation system.

4. This assumes the plant manager's income is a function of plant profits.

5. The model is a pure monopoly model if input prices are independent of industry output, C = 0.

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