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# INVESTMENTS IN OLIGOPOLY: WELFARE EFFECTS AND TESTS FOR PREDATION

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## 1. Introduction

It is now widely recognised that actions that increase welfare under competition or blockaded monopoly can decrease welfare under oligopoly. In an oligopoly, part of a firm's gain from an action is due to altering industry equilibrium in its favour, to the disadvantage of rivals—whether incumbents or potential entrants. Consumers may also suffer due to a higher price if the firm's action drives out a rival or deters it from entering.

Many such actions involve the spending of a fixed, sunk cost in order to reduce marginal cost. This makes the firm a tougher competitor and thereby can induce rivals, actual or potential, to scale back their planned expansion. Examples of such actions include the overpurchasing of capacity (e.g., Spence (1977), Dixit (1980), Eaton and Lipsey (1981)), of inventories (Saloner (1986)), and of R&D (Brander and Spencer (1983), Spence (1984)). Overproduction in early periods to reduce marginal later cost via learning by doing can also serve such a strategic purpose (Fudenberg and Tirole (1983)). Other examples and references are presented in Shapiro's (1987) survey of oligopoly theory. For brevity, I refer to all such fixed-cost expenditures that reduce marginal cost as "investments."

The investments mentioned above do not raise rivals' costs. This contrasts with the overpurchase of inelastically-supplied inputs such as patents, exhaustible resources, and location-specific assets (see, e.g., Williamson (1968), Gilbert and Newbery (1982), Lewis (1983), Salop and Scheffman (1983)). Nevertheless, our investments can reduce welfare by raising the equilibrium industry cost or reducing the equilibrium output.

The general tradeoffs involved are familiar to most researchers in the area. For instance, expanding capital to deter entry may increase the incumbent's cost but avoid the duplication of a fixed entry cost; it also may raise equilibrium price compared to allowing entry. Beyond identifying the basic tradeoffs, however, the literature leaves us fairly uninformed about the overall welfare effects of investments in oligopoly. Many of the papers focus on whether strategic investments are feasible and profitable, rather

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than on welfare. Those that do look at welfare typically proceed by assuming a particular ologopoly interaction (usually Cournot) and deriving the resulting equilibrium (e.g., von Weizsäcker (1980), Brander and Spencer (1983), Schwartz and Baumann (1988)).

In this paper I suppress the oligopoly interaction and frame the analysis in terms of welfare decompositions involving changes in price, outputs and costs. This clarifies the underlying economic forces. A related, important advantage of this approach is that it permits some inferences about the welfare change based solely on variables that might be observable, such as price, outputs and only local values of firms' costs. The paper is similar in spirit to Perry's (1984) and Mankiw and Whinston's (1986) independent analyses of the forces that tend to create excessive entry into homogeneous-good markets. But I do not require symmetry or scale economies and allow the number of firms to change or remain the same. In addition I use the model to evaluate tests for predatory investment, as explained shortly.

Section 2 of the paper presents a simple, homogeneous-good duopoly model, where one firm makes an investment decision and in response the rival firm decides to stay in the market or exit. When deciding whether to invest, the first firm foresees the second-period equilibrium. In some respects the model is more restrictive than usual, notably, the identity of the investing firm and the timing and type of investment opportunity available are assumed exogenous. However, the cost and demand conditions assumed are quite general and no specific oligopoly interaction is imposed.

Section 3 presents the welfare analysis. I concentrate on why welfare can fall even if price falls, that is, why the loss to the rival can outweigh the gains to consumers—in contrast to the competitive model. I identify two conditions necessary for investments that lower equilibrium price also to reduce welfare: a reshuffling of output away from the rival towards the investing firm and a gap between price and the rival's marginal cost in the new equilibrium (Remarks 1 and 2). Next, I provide a sufficient condition for welfare to increase in the presence of output reshuffling and a price-cost gap for the rival (Remark 3). On the negative side, I show that welfare can be reduced even by costless investments (zero fixed cost) that leave the rival in the market (Remark 4). A specific oligopoly interaction is imposed only in Remark 5, which shows what welfare inferences can be made by observing whether the rival exits and whether he possesses scale economies, assuming the oligopoly interaction is Cournot.

I next address predatory investment. Most economists' intuitive notion of what constitutes predation is an action whose profitability hinges on eliminating a competitive constraint. Ordover and Willig (1981) propose a test for predatory behaviour based on this intuitive notion ((see Ordover and Saloner (1987) for further discussion of the test). Using the basic model of Section 2, I examine in Section 4 the welfare basis for this view of predation. After formulating Ordover and Willig's test in a general way that admits various interpretations of the competitive constraint that the firm eliminates through its investment, I show that any version of the test will generate errors (Proposition 1). I then consider two specific interpretations, discuss their shortcomings, and identify superior price-regulation rules (Remark 6). Concluding remarks are offered in Section 5.

## 2. The model

Consider a homogeneous product with price a function of total output $p = P(q)$, where $P' < 0$, for all $q$ such that $P(q) > 0$. Throughout, upper case letters will denote functions and lower case will denote values. $P$ is constant over time and commonly known. There are two firms, $A$ and $B$, and two periods: pre-investment and post-investment, denoted 1 and 2.

In period 1, each firm $j$ has a marginal cost function $MC_1^j(q)$ that is positive and non-decreasing for all $q$, $j = A, B$. There is also a fixed cost $g^j \geq 0$ that can be avoided through shutdown but is incurred for any positive output. Firm $j$'s total cost function, denoted $C_1^j(q)$, thus includes both marginal costs and $g^j$, with scale economies existing (over some range) if $g^j > 0$. There may also be fixed costs that are sunk; such sunk fixed costs could explain why the industry is initially oligopolistic but will not affect the welfare analysis.

In the initial equilibrium both firms are active, producing positive outputs $(q_1^A, q_1^B)$ and earning positive net profits $v_1^j$ given by

$$v_1^j = V_1^j(q_1^A, q_1^B) > 0,$$

where $V_1^j$ denote firm $j$'s profit function. This dupoly equilibrium may reflect any non-cooperative interaction. At the end of period 1 firm $A$ discovers an investment opportunity which involves incurring a fixed and non-recoverable cost, $f$, to reduce marginal cost. If firm $A$ does not invest, its costs remain unchanged and the initial equilibrium persists. If firm $A$ does invest, its marginal cost function becomes $MC_2^A(q)$ which for all $q$ is positive, non-decreasing, and satisfies $MC_2^A(q) < MC_1^A(q)$. The total cost function with the investment, denoted $C_2^A(q)$, reflects both $MC_2^A$ and $f$. (The recoverable fixed cost $g^A$ is assumed unchanged, but we could equivalently allow it to change and interpret $f$ as the fixed cost of investing gross of any charge in $g^A$.)

If firm $A$ invests, firm $B$ observes $MC_2^A$ and calculates the new duopoly outputs that would prevail if it stayed in the market, $(\bar{q}_2^A, \bar{q}_2^B)$. It exits if

$$V^B(\bar{q}_2^A, \bar{q}_2^B) \leq 0, \tag{2.1}$$

where $V^B$ is firm $B$'s unchanged profit function. Thus, if firm $A$ invests the period 2 equilibrium will be

$$(q_2^A, q_2^B) = \begin{cases} (q_2^m, 0) & \text{if (2.1) is satisfied} \\ (\bar{q}_2^A, \bar{q}_2^B) & \text{otherwise,} \end{cases}$$



where $q_2^m$ denotes $A$'s simple monopoly output given $MC_2^A$. Since $MC_2^A(q) < MC_1^A(q)$, the sign of $q_2^m - (q_1^A + q_1^B)$ is ambiguous. That is, if firm $B$ exits then equilibrium price can fall or rise. Firm $B$ will not re-enter even if price rises because it recognizes that outputs would revert to the duopoly levels $(\bar{q}_2^A, \bar{q}_2^B)$ if it re-entered.

Firm $A$ will invest if its (foreseen) profit is no lower, i.e., if

$$V_2^A(q_2^A, q_2^B) = v_2^A \geq v_1^A. \tag{2.2}$$

Note that the profit function $V_2^A$ reflects $C_2^A$, that is, reflects both the lower marginal cost from the investment and the fixed cost $f$. Although $f$ becomes sunk once incurred, it is avoidable ex ante and must therefore enter both firm $A$'s profit calculation and the overall welfare calculation.

Welfare is viewed as the area under the demand curve minus total cost,

$$w = \int_0^q P(x)\,dx - C^A(q^A) - C^B(q^B), \tag{2.3}$$

where $q = q^A + q^B$ and period subscripts have been suppressed. Welfare can also be expressed as total surplus,

$$\begin{aligned} w &= \int_0^q [P(x) - p]\,dx + [pq^A - C^A(q^A)] + [pq^B - C^B(q^B)] \\ &= s + v^A + v^B, \end{aligned} \tag{2.4}$$

where $p$ is the prevailing price, $P(q)$, $s$ denotes consumer surplus, and $v^A$ and $v^B$ denote profits. The difference in welfare moving from the "no investment" to the "investment" regime, denoted $\Delta w$, is determined by the magnitudes of $\Delta s$, $\Delta v^A$ and $\Delta v^B$. These terms depend on the oligopoly interaction and on the parameters $MC_1^A$, $MC_2^A$, $MC^B$, $P$, $f$, and $g^B$. Since each of these can vary independently, evaluating $\Delta w$ requires considerable information. Nonetheless, the next section shows that inferences can be made about the *sign* of $\Delta w$ using only limited information that might be available to policymakers.

## 3. Welfare inferences from limited information

### A. *Rival stays in the market*

If firm $B$ stays in the market following firm $A$'s cost decrease then, assuming the oligopoly interaction remains unchanged, equilibrium should fall.[1] Welfare, however, can increase or decrease. The losing party

[1] Dixit (1986) analyzes comparative statics for a general oligopoly model where the oligopoly interaction is represented by a conjectural-variations parameter. For homogeneous products he shows that if stability conditions are met, the "expected" comparative statics emerge, e.g., a fall in marginal cost will reduce price. The stability conditions involve the conjectural variations parameter, as well as costs and demand.

obviously is firm $B$, but it is not evident why its losses can outweigh the gain to firm $A$ and to consumers. For example, in the short-run competitive model with an upward-sloping industry supply curve, any loss to rivals caused by one firm's marginal-cost reduction would be outweighed by increased consumer surplus due to the price decrease.

### (a) *Sufficient conditions for welfare to increase*

To clarify the underlying forces, use (2.3) to decompose the change in welfare as

$$\Delta w = \int_{q_1}^{q_2} [P(x) - p_2]\,dx + p_2(q_2 - q_1) - \Delta c^A - \Delta c^B,$$

where $\Delta c^j = C_2^j(q_2^j) - C_1^j(q_1^j)$, $j = A, B$. Recalling that $q_t = q_t^A + q_t^B$, $t = 1,2$, and rearranging gives

$$\Delta w = \int_{q_1}^{q_2} [P(x) - p_2]\,dx + (p_1 - p_2)q_1^A + [p_2 q_2^A - p_1 q_1^A - \Delta c^A] + [p_2 q_2^B - p_2 q_1^B - \Delta c^B]. \quad (3.1)$$

Since the third term on the right equals $\Delta v^A$ we have

$$\Delta w = \underbrace{\int_{q_1}^{q_2} [P(x) - p_2]\,dx}_{T} + \underbrace{(p_1 - p_2)q_1^A}_{Y} + \Delta v^A + m, \qquad m = \int_{q_1^B}^{q_2^B} [p_2 - MC^B(x)]\,dx. \quad (3.2)$$

For $q_2 > q_1$ (price falling), the first two terms on the right are positive. The third, $\Delta v^A$, is always non-negative by (2.2). The only uncertain term is $m$ (for "mischief"). Term $m$ is the change in firm $B$'s profit that does not affect consumers. It reflects not the price drop but the reshuffling of output $q_1^B - q_2^B$ from firm $B$ to firm $A$. The gains to firm $A$ from such reshuffling can be smaller than firm $B$'s loss, because of the investment cost $f$ or because firm $A$'s new marginal cost still exceeds firm $B$'s, as discussed shortly. A case where $m < 0$ is shown in Fig. 1. The figure is drawn so that $p_2 > MC^B$ over the entire range of $B$'s output cutback, as would arise for example under Cournot interaction with $MC^B$ constant or relatively flat. (The other symbols in Fig. 1 become relevant shortly.)

Inspection of expression (3.2) and term $m$ gives some sufficient conditions for welfare to increase if price falls. If firm $B$ does not reduce output



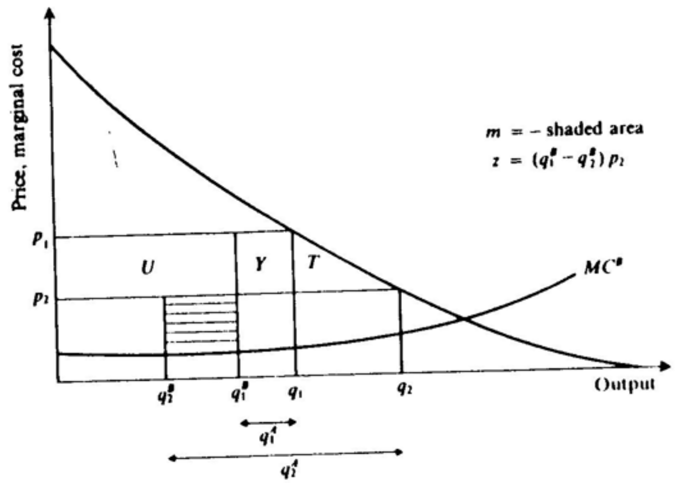


FIG. 1

($q_2^B \geq q_1^B$) then term $m \geq 0$, because $MC^B$ is non-decreasing and $p_2 \geq MC^B(q_2^B)$ or else firm $B$ would have chosen output below $q_2^B$.[2] Therefore:

*Remark* 1

A profitable, price-reducing investment increases welfare if the rival firm does not decrease its output: given $p_2 < p_1$, if $q_2^B \geq q_1^B$ then $w_2 > w_1$.

Intuitively, any loss to the rival firm now reflects only the price drop and is captured entirely by consumers. Thus, a price-reducing investment can decrease welfare only if it reshuffles output away from the rival.[3]

If output reshuffling does occur ($q_2^B < q_1^B$), the sign of $m$ is uncertain in general. But the fact that $m \geq 0$ if $MC^B(q_2^B) = p_2$ implies:

*Remark* 2

A profitable, price-reducing investment increases welfare if in the new equilibrium the rival equates price and marginal cost: given $p_2 < p_1$, if $MC^B(q_2^B) = p_2$ then $w_2 > w_1$.

[2] This revealed preference argument assumes that a firm does not expect its output contraction to reduce price by inducing a more than offsetting expansion by the rival. That is, firm $i$ globally expects $\partial q^j/\partial q^i \geq -1$, $i, j = A, B$. This is an innocuous restriction, satisfied by most plausible interactions. For instance, Cournot behaviour has $\partial q^j/\partial q^i = 0$ and price-taking behaviour can be represented as $\sum_{j \neq i} \partial q^j/\partial q^i = -1$.

[3] Mankiw and Whinston (1986) call such output reshuffling "business stealing" and show that, if price exceeds marginal cost, this can easily lead to excessive entry into a homogeneous-good market by identical firms with fixed costs. The importance of output reshuffling has also been recognized by trade theorists, as discussed shortly.

Note that Remark 1 explains Vives' (1985) finding that, in a model of sequential entry where early entrants are committed to maintaining their initial outputs, free entry must increase welfare despite the duplication of fixed costs.

The competitive model, where all firms act as price-takers throughout, is a special case covered by Remark 2 if we interpret $MC^B$ as the marginal cost function of all rival firms. Any output cutback by rivals is then efficient, hence welfare must increase. For welfare to decrease when price falls, it is therefore necessary both that the rival contract and that its marginal cost be below price in the *new* equilibrium.

These conditions can easily arise under imperfect competition and can cause welfare to fall, as shown in the Cournot model of Appendix 1. However, expression (3.2) yields a sufficient condition for welfare to increase even under imperfect competition. Importantly, this condition uses only variables that are fairly observable:

*Remark* 3

A profitable, price-reducing investment increases welfare if the price change times the investing firm's initial output exceeds the lower price times the rival's output drop: given $p_2 < p_1$, if $(p_1 - p_2)q_1^A > p_2(q_1^B - q_2^B)$ then $w_2 > w_1$.

This condition follows from expression (3.2), since $p_2 < p_1$ (hence $q_2 > q_1$) implies $\Delta w > (p_1 - p_2)q_1^A + m$, and since $m > -p_2(q_1^B - q_2^B)$ when $q_2^B < q_1^B$, because firm $B$'s cost is reduced. Economically, Remark 3 can be interpreted in terms of the positive and negative externalities imposed by firm $A$. Since firm $A$'s profit does not fall, welfare increases if the gain to consumers exceeds the loss to the rival. That portion of the rival's loss arising from the price drop is a transfer to consumers; this is $(p_1 - p_2)q_1^B$, rectangle $U$ in Fig. 1. Consumers gain additionally from increased industry output, "triangle" $T$, and from the price drop on firm $A$'s initial output, rectangle $Y$. The rival's profit change that is due solely to output reshuffling—and hence not affecting consumers—is area $m$. This is the loss in revenue from reducing output (evaluated at the lower price) plus any cost savings. Clearly the revenue loss, $p_2(q_1^B - q_2^B)$ or area $Z$, bounds the profit loss. By comparing $(p_1 - p_2)q_1^A$ with $p_2(q_1^B - q_2^B)$ Remark 3 thus compares: (i) part of those gains to consumers that were not transfers from the rival with (ii) an *upper bound* on term $m$, that loss to the rival that was not a transfer to consumers. Any information on the rival's cost savings from reducing output obviously would permit a tighter bound on $m$ than $p_2(q_1^B - q_2^B)$, and correspondingly yield a more powerful test than Remark 3.

Remark 3 suggests that welfare is less likely to decrease when $q_1^A$ is high relative to $q_1^B$, i.e., when the investing firm is relatively large. Intuitively, a small firm can find an investment profitable largely because it reshuffles output away from the large firm; a reshuffling which can be socially inefficient. In contrast, the gain to a large firm must come largely from reducing its production costs, since there is little output to be reshuffled from the small rival. This suggests adopting a more permissive approach to investments undertaken by the larger rather than smaller firms in a market, a somewhat



counterintuitive conclusion. Recall, however, that the analysis is predicated on equilibrium price falling, so that the only possible negative externality is on rival firms. In contrast, a large firm would gain more than a small one from an investment that permitted an increase in price by inducing the exit of a third rival. A rigorous discussion of such differential incentives to raise price, however, would require moving beyond the present duopoly context.

(b) *Why welfare can decrease when price falls*

The analysis so far is in terms of pecuniary externalities. Non-offsetting pecuniary externalities, of course, reflect real changes—in total output or cost. It is also revealing to examine the problem in these terms.

Let: $q_2 - q_1 = \delta > 0$, $q_2^B - q_1^B = -\alpha$, so $q_2^A = q_1^A + \delta + \alpha$. The normal case has $q_2^B - q_1^B < 0$ hence $\alpha > 0$. Suppressing the variables of integration hereafter to reduce notation, decompose the change in firm $A$'s cost as

$$C_2^A(q_2^A) - C_1^A(q_1^A) = \int_0^{q_1^A} [MC_2^A - MC_1^A] + \int_{q_1^A}^{q_1^A+\alpha} MC_2^A + \int_{q_1^A+\alpha}^{q_1^A+\alpha+\delta} MC_2^A + f$$

Since change in welfare is the increased area under the demand curve minus the change in firm $A$'s and firm $B$'s costs, it can be expressed as

$$\Delta w = \underbrace{\left[\int_{q_1}^{q_1+\delta} P - \int_{q_1^A+\alpha}^{q_1^A+\alpha+\delta} MC_2^A\right]}_{G} + \underbrace{\int_0^{q_1^A} [MC_1^A - MC_2^A]}_{H}$$

$$- \underbrace{\left[\int_{q_1^A}^{q_1^A+\alpha} MC_2^A - \int_{q_1^B-\alpha}^{q_1^B} MC^B\right]}_{L} - f \quad (3.3)$$

Term $G > 0$ since $P(q_1 + \delta) \geq MC_2^A(q_1^A + \alpha + \delta)$ and since $P' < 0$ while $MC_2^{A\prime} \geq 0$. This term reflects the net social value of the industry's output expansion. Term $H \geq 0$ since $q_1^A \geq 0$ and $MC_1^A > MC_2^A$. This term reflects the social value of the decrease in variable cost of producing firm $A$'s initial output. Term $L$ reflects the change in industry variable cost due to reshuffling the output $\alpha$ between the firms. It can take any sign, depending on the relation between the marginal cost functions $MC_2^A$ and $MC^B$.

Expression (3.3) reveals that the scope for welfare decrease is greater when: the expansion in industry output ($\delta$) is smaller; the investor's initial output ($q_1^A$) is smaller; the output reshuffled away from the rival ($\alpha$) is larger; and the investment cost ($f$) is larger. The precise relation between these magnitudes depends on the functional forms and on the oligopoly interaction assumed. Appendix 1 presents a Cournot model with linear demand and constant marginal costs (but not necessarily identical, either before or after the investment) and shows that the welfare loss from a price-reducing investment can be large, exceeding 15 per cent of initial welfare. This maximum loss incurs when the fixed cost $f$ is large enough to consume the entire increase in operating profits.[4]

(c) *Costless price-reducing investments*

Given the prominent role of fixed costs in generating inefficiency in oligopolies, notably through duplicative entry (e.g., von Weizsacker (1980), Mankiw and Whinston (1986)), it is tempting also to attribute the welfare decrease from a price-reducing investment entirely to the fixed cost $f$. This is incorrect.

*Remark* 4

A profitable, price-reducing investment can decrease welfare even if the investment is costless ($f = 0$).

An example is provided in the Cournot model of Appendix 1, but the underlying force can be seen from expression (3.3). When $f = 0$, $\Delta w < 0$ implies that $L > 0$, that is, even after the investment it is more expensive to have firm $A$ rather than firm $B$ produce the reshuffled-output $\alpha$, since $A$'s new marginal cost is still higher than $B$'s.[5]

Findings similar to Remark 4 have been recently obtained independently by several authors in somewhat different contexts. Katz and Shapiro ((1985), Proposition 4) show that welfare can fall if an innovating firm grants its cost-reducing innovation also to a second firm whose marginal cost remains higher than the innovator's. Clarke (1987), using a linear Cournot model with constant but different marginal costs (as in Appendix 1 here), proves that welfare can fall due to entry by a higher marginal-cost firm (such entry can be viewed as a decrease in that firm's costs from previously prohibitive levels). In a formally-equivalent Cournot model (instead of entrants having a higher production cost, consumers incur a per unit cost when switching to an entrant's product), Klemperer (1988) shows additionally that with linear demand welfare is more likely to fall the larger is the number of entrants and that, for any demand curve, welfare must fall if the entrant's new output is small (the social value of increased output is then necessarily less than the loss from output switching). Malueg (1987), in a model similar to Clarke's, finds that trading of emission credits can reduce welfare if the resulting cost decreases occur disproportionately to the higher-cost firms. In all these examples equilibrium price falls, and the decrease in welfare arises entirely from the reshuffling of output towards higher-cost firms.

[4] Expression (3.3) does not bring out the constraint that the investment must be profitable, $\Delta v^A \geq 0$. To see the relation between output reshuffling, the investment's profitability and the change in welfare, let $\Delta D$ denote consumers' valuation of the increased industry output, the area under the demand curve over the interval $[q^1, q^1 + \delta]$. Let $\Delta g = \Delta D - \delta p^2 + (p^1 - p^2)q_1^A > 0$ denote the portion of increased consumer surplus due to the added output $\delta$ and to the fall in price on firm A's initial output. Firm A's revenue change is $(p_2 - p_1)q_1^A + (\delta + \alpha)p_2 = \Delta D - \Delta g + \alpha p_2$, so change in its profit is $\Delta v^A = \Delta D - \Delta c^A - \Delta g + \alpha p_2 \geq 0$. If the rival reduces output then $\alpha p_2 > 0$, which permits $\Delta v^A \geq 0$ even if $\Delta D - \Delta c^A < 0$. That is, the revenue firm A gained by reshuffling output away from firm B can make the investment privately profitable even if consumers' valuation of the extra industry output is less than the increase in firm A's cost.

[5] In the model of Appendix 1, the maximum welfare loss from a costless investment occurs if the reduction in firm A's marginal cost is "moderate"—large enough to create significant output reshuffling away from firm B but small enough to leave $MC_2^A$ significantly above $MC^B$ (in order to outweigh the positive term $G$ that increases as $MC_2^A$ decreases). For costless investments, welfare obviously must increase if firm A's new marginal cost curve lies below and does not cross firm B's.

For costly investments ($f > 0$), however, $MC_2^A < MC^B$ is consistent with welfare decreasing, since savings in variable costs to the industry can be consumed by the fixed cost $f$. In fact, in the model of Appendix 1 the greatest welfare loss occurs for costly investments that yield $MC_2^A = MC^B$ (so a fortiori $\Delta w < 0$ for some $MC_2^A < MC^B$).



The importance of such inefficient output reshuffling was recognized by trade theorists much earlier. Viner (1950) and Lipsey (1960) showed that the formation of a partial customs union can create an undesirable trade diversion which can outweigh the gains from trade creation. Similarly, Johnson (1967) showed that technical progress in the import-competing industry can reduce welfare if that industry is initially protected by a tariff.[6]

(d) *Inefficient vertical mergers under fixed-proportions technology*

The possibility of inefficient output reshuffling also has an interesting implication for vertical mergers. It is widely believed that a vertical merger cannot reduce welfare if production is subject to fixed-proportions technology, since the sole effect of a vertical merger would be to eliminate any pricing distortion upstream. This intuition is guided by the successive monopoly model (e.g., Warren-Boulton (1978)). Our "costless investment" discussion shows that this intuition can fail when the downstream stage is an oligopoly rather than a monopoly.

Consider one firm that is vertically integrated and has a low-cost internal input supply and an unintegrated rival that purchases from a monopolistic supplier. Imperfect competition (e.g., Cournot) enables the unintegrated firm to survive even though its marginal cost is higher. A vertical merger with the supplier will reduce the transfer price and thus the perceived marginal cost, but can still leave marginal cost above the rival's (if the acquired monopolist supplier had high cost). Inefficient output reshuffling can then reduce welfare, as with a costless investment (Remark 4).[7] Indeed, welfare can fall more easily here since the decrease in marginal cost reflects only a lower transfer price, not a real cost saving.

[6] I am grateful to Jonathan Eaton for alerting me to this trade literature. Eaton and Panagariya (1982) provide some sufficient conditions for welfare to increase following technical progress or factor growth in the presence of initial distortions, an exercise similar in spirit to my Remarks 1 and 3 above.

[7] Salinger (1988) shows that a vertical merger can reduce welfare if both stages are Cournot oligopolies and all downstream firms buy from the same input suppliers. He demonstrates that a merged entity will choose not to supply inputs to unintegrated downstream rivals. Consequently, the price of inputs can rise enough to increase the final price (despite the expansion by the merging firm) and thereby reduce welfare. The source of welfare loss I discuss is obviously different, since downstream price falls.

The scope for welfare loss nevertheless seems quite limited. For instance, in the Cournot model of Appendix 1, the maximum welfare loss from a costless investment is only 6.7 per cent.[8]

### B. *Rival exits the market*

Two differences are introduced if firm $A$'s investment makes firm $B$ exit. Firstly, equilibrium price can fall or rise.[9,10] Secondly, firm $B$'s fixed but avoidable cost, $g^B$, is saved and must be added in (3.2) or (3.3) to compute the change in welfare. Observing whether firm $B$ exits or not can provide some guidance about the change in welfare if the oligopoly interaction is Cournot.

*Remark* 5

Assume the cost conditions of Section 2: $g^A$, $g^B \geq 0$ and $MC_1^{A'}(q)$, $MC_2^{A'}(q)$, $MC^{B'}(q) \geq 0$. Suppose also that demand is concave, $P'(q) \leq 0$. Given Cournot interaction:

(i) with no scale economies to the rival ($g^B = 0$), if the rival exits then price must fall and welfare must rise;

(ii) regardless of scale economies to the rival, if the rival stays in then price must fall but welfare can rise or fall;

(iii) with scale economies to the rival ($g^B > 0$), if the rival exits then price and welfare can rise or fall, in any combination.

Remark 5, whose proof is available on request, might seem counterintuitive. Comparing parts (i) and (ii), one might have expected a better welfare outcome when the rival stays in the market rather than exits. Comparing (i) and (iii), one might have expected a better welfare outcome when the rival exits under scale economies, since here these entail a positive fixed cost, $g^B$, which is avoided if $B$ exits. The intuition behind Remark 5 is this. A rival with no scale economies exits under Cournot behaviour only if we have what Arrow (1962) called a "drastic" innovation: the investing firm's cost reduction is large enough to make its monopoly price no higher than the rival's minimum average cost. Any output reshuffling away from the rival is

[8] This figure does not understate the maximum loss from a vertical merger, by wrongly treating the merging firm's cost reduction as a social saving, because the 6.7 per cent was obtained assuming $q_1^A = 0$. Moreover, this maximum percentage figure is obtained assuming a positive fixed cost to the rival, $g^B$, which reduces the base level of welfare.

[9] Threat of hit-and-run entry by firm $B$, as under perfect contestability (Baumol, Panzar and Willig (1982)), would prevent firm $A$ from raising price. This threat is absent, however, if firm $A$ can reduce price rapidly in response to $B$'s re-entry ((Schwartz and Reynolds (1983), Schwartz (1986)). In that case, firm $B$'s expected profit is governed by the duopoly point $(\bar{q}_2^A, \bar{q}_2^B)$ and this profit is nonpositive for exit-inducing investments.

[10] Thus far I have assumed that the duopoly interaction remains unchanged: the equilibrium changes only due to the change in costs. However, the oligopoly interaction itself might change. Specifically, the investing firm's reduced marginal cost might enable it to threaten the rival more credibly into reducing output. In such a case, equilibrium price could rise even if the rival remained in the market. A pattern of rival in and price rising would strongly suggest that the investment did change the nature of the oligopoly interaction, since the decrease in one firm's marginal cost would otherwise be expected to reduce price.



then efficient. If the rival stays in the market, or if it exits and has scale economies, we cannot infer much about the investing firm's new marginal cost and therefore cannot conclude that all output reshuffling was efficient.

## 4. Testing for predatory investment

### A. *A class of predation tests*

Ordover and Willig (1981, "OW") propose an interesting judicial test to determine whether an innovation, or any other investment, is "predatory". The notion of predatory investment cannot be dismissed out of hand. By investing to reduce its variable costs, a firm could set a price below rivals' costs, but above its own variable cost, thereby circumventing rules against predatory pricing based on comparing price and variable cost (rules associated with Areeda and Turner (1978)). Yet the firm's price could be below its average total cost when the investment's fixed cost is included, giving the investment a predatory flavour. Allegations of predatory investment have been made, for example, in one of the leading antitrust cases of recent times—by Control Data Corporation against IBM's introduction of the 360/90 supercomputer in response to Control Data's 600 (Pittman (1984)).

OW's test finds an innovation predatory if, and only if, it "sacrifices part of the profit that could be earned, under competitive circumstances, were the rival to remain variable, in order to induce exit and gain consequent additional monopoly profit (OW, pp. 9–10)."[11] The test tracks the widespread intuition that a practice should be viewed as predatory if and only if its profitability hinges on eliminating a competitive constraint, e.g., on forcing the rival's exit. For further discussion of non-price predation and OW's test see the survey of predation and antithrust by Ordover and Saloner (1987).

I am interested in scrutinising the welfare properties of OW's test. The slippery part of the test is the hypothetical benchmark, ". . . profit that could be earned . . . were the rival to remain viable." OW define the rival as viable if he can costlessly re-enter the market, i.e., if he faces no re-entry barriers such as set-up costs (OW, p. 13). The rival's viability therefore means that the investing firm can capture the entire market (rival produces zero) but cannot raise the price above the rival's average cost curve, otherwise the rival would profitably re-enter.

I will consider a class of tests that captures this and other interpretations

[11] OW (pp. 13–14) illustrate their test with the following example. Suppose that pre-innovation duopoly profit is 105. Consider an innovation that makes the rival exit and yields the innovator monopoly profit of 110, but would yield only 100 were the rival to remain viable rather than exit. The innovation would be found predatory under the test since it is profitable only because the rival is no longer viable. If the pre-innovation duopoly profit were less than 100, the same innovation would be found not predatory because it would be profitable even if the rival did remain visible.

of the rival's viability. For instance, "rival's viability" might mean that the rival continued producing at some positive level.

Consider the model of Section 2 where firm $A$ chooses between two actions, "invest" and "not invest." Choosing "not invest" maintains the initial equilibrium profit, $v_1^A$, while choosing "invest" yields the foreseen new equilibrium $(q_2^A, q_2^B)$, which could involve firm $B$ exiting $(q_2^B = 0)$ or staying in. Firm $A$ chooses "invest" and the associated profit function $V_2^A$ if doing so is (weakly) profitable given the new equilibrium, i.e., if $V_2^A(q_2^A, q_2^B) \geq v_1^A$. I represent the rival's viability, or any other constraint on firm $A$, by a hypothetical pair of outputs $(q_h^A, q_h^B)$ that need not equal the actual new equilibrium outputs. For test purposes, $V_2^A$ is evaluated at these hypothetical outputs and is compared with $v_1^A$. The formulation below can address investments that leave firm $B$ in the market and those that induce $B$ to exit (as in OW's experiment).

Consider a class of tests that finds an investment

$$\begin{aligned}&\textit{predatory} \Leftrightarrow V_2^A(q_h^A, q_h^B) < v_1^A\\ &\text{where: } q_h^A \text{ maximizes } V_2^A(q^A; q_h^B) \text{ subject to } q^A \geq q_r\\ &\qquad q_h^B \geq 0 \text{ and } q_r \geq 0 \text{ are outputs specified by policymaker.}\end{aligned} \tag{4.1}$$

Any test in (4.1) is characterized by a pair of outputs $q_h^B$ and $q_r$. OW's view of rival's viability, that the investment causes the rival to shut down but his threat of expansion prevents the investor from raising price above some level $p_r$, can be captured in (4.1) by setting $q_h^B = 0$ and $q_r$ at the level satisfying $p_r = P(q_r)$.

### B. *The absence of error-free tests*

In order to implement any test in (4.1), the policymaker must know firm $A$'s initial profit level $v_1^A$ and its new profit function $V_2^A$, which in turn depends on market demand and $A$'s new cost function. Given that such considerable information must be available for implementing the test in the first place, one might wonder if a perfect version of the test could be devised by letting the test outputs $q_h^B$ and $q_r$ be functions of this information. Denote by $X$ the set of all possible information states concerning firm $A$'s initial profit, market demand, and firm $A$'s cost function in both periods. This information is sufficient for knowing $v_1^A$ and the function $V_2^A$. The only relevant information excluded from $X$ concerns firm $B$'s cost function, since if this information were also available an explicit welfare calculation could be made. With the plethora of information admitted, can a perfect test be found? The answer is given by the following impossibility result.

*Proposition* 1: For any pair of functions $(q_h^B, q_r): X \to R^2$, there exist specifications $x \in X$ and oligopoly interactions such that the test in (4.1) will

I. find "predatory" some investments that increase welfare; or

II. find "not predatory" some investments that decrease welfare.



*Proof*

Consider the Cournot model with price $p = a - q$ and constant marginal costs $c_1^A = c^B$, $c_2^A < c_1^A$, recoverable fixed costs $g^A$, $g^B$, and investment cost $f$. Then $X$ is the set of all vectors $(a, c_1^A, c_2^A, g^A, f)$. Consider two vectors of parameter values $y = (x, c^B; g^B)$, $\bar{y} = (x, c^B; \bar{g}^B)$ where $g^B < \bar{g}^B$, $x \in X$, and such that firm $A$'s investment satisfies the following conditions:

(i) for both $y$ and $\bar{y}$, following $A$'s investment firm $B$ exits;

(ii) for both $y$ and $\bar{y}$, $V_2^A(q_2^m, 0) = v_1^A$;

(iii) for $y$ welfare decreases but for $\bar{y}$ welfare increases.

Existence of vectors $y$ and $\bar{y}$ is shown in Appendix 1, Section B. (Note that the equality in (ii) is preserved as $g^B$ varies since $B$'s fixed cost does not affect $A$'s initial profit $v_1^A$.) Given $x$ and functions $q_h^B$ and $q_r$, we consider two exhaustive possibilities, for test purposes firm $A$ is either unconstrained or constrained:

(a) $q_h^B(x) = 0$ and $q_r(x) \leq q_2^m(x)$ (firm $A$ unconstrained)

(b) $q_h^B(x) > 0$ or $q_r(x) > q_2^m(x)$ (firm $A$ constrained).

Suppose (a). Then $(q_h^A, q_h^B) = (q_2^m, 0)$, hence $V_2^A(q_h^A, q_h^B) = V_2^A(q_2^m, 0) = v_1^A$, so the test finds the investment "not predatory." For $y$ this implies error II. Suppose (b). Then $(q_h^A, q_h^B) \neq (q_2^m, 0)$, hence $V_2^A(q_h^A, q_h^B) < V_2^A(q_2^m, 0) = v_1^A$, the equality by (ii). Thus, the test finds the investment "predatory." For $\bar{y}$ this implies error I. Q.E.D.

The basic problem is that an investment that breaks even in the unconstrained monopoly equilibrium can decrease or increase welfare. For it to increase welfare it must be price-reducing; but this does not ensure that welfare increases, since the gains to consumers must be compared with the decrease in the rival firm's profit. In general, making this comparison requires knowing the rival's cost function, even if the oligopoly interaction were known (Cournot in the proof). Some exceptions were noted in Section 3.

Observe that since desirable investments can break even only in an unconstrained-monopoly equilibrium, *any* constraint uniformly applied will deter some desirable investments. For example, forced licensing to competitors, restrictions on patent life, and requirements to expand output will all force a firm away from the monopoly solution and thereby render unprofitable some desirable investments.

### C. *Examples and superior rules*

The family of tests described in (4.1) allows for various constraints on the minimum size that the rival can be squeezed to, since any $q_h^B \geq 0$ is permitted. Ordover and Willig envisage allowing the investing firm to drive out the rival, $q_h^B = 0$, but evaluating the firm's profit at a price no higher than some level $p_r$ (i.e., requiring $q^A \geq q_r$).

Consider two particular test prices, $p_r$:

(a) $p_r = p_1$ (and $q_h^B = 0$). Here firm $A$'s profit is computed, for test purposes, assuming it cannot raise above the initial equilibrium level.

(b) $p_r = \min AC^B$ (and $q_h^B = 0$). Here firm $A$ cannot raise price above firm $B$'s minimum average cost or, if $AC^B$ is everywhere decreasing, the price at which it intersects demand. This interpretation of $p_r$ is motivated by contestability theory which states that, with no sunk costs, threat of entry will prevent a monopolist from raising price above a potential entrant's average cost.

To get a better sense as to why both test prices will generate errors, consider cases where firm $B$ exits in the new equilibrium (and firm $A$ becomes an unconstrained monopolist). Then welfare in the new equilibrium, $w_2$, can be expressed as consumer surplus, plus $A$'s profit had firm $A$ supplied $q_r$, plus a term reflecting the difference between $q_r$ and $A$'s actual new output $q_2$. Again suppressing the variables of integration, we have

$$w_2 = \int_0^{q_r} P - p_r q_r + v_r^A + \int_{q_r}^{q_2} (P - MC_2^A) \quad \text{where} \quad v_r^A = p_r q_r - C_2^A(q_r).$$

Since $w_1 = \int_0^{q_1} P - p_1 q_1 + v_1^A + v_1^B$, change in welfare can be expressed as

$$\Delta w = \int_{q_1}^{q_r} P - p_r(q_r - q_1) + \int_{q_r}^{q_2} (P - MC_2^A) + (p_1 - p_r)q_1 - v_1^B + (v_r^A - v_1^A). \tag{4.2}$$

The finding of test (4.1) will be

$$\begin{aligned} &\text{when } p_2 > p_r (q_2 < q_r)\text{: } \textit{predatory} \Leftrightarrow v_r^A < v_1^A \\ &\text{when } p_2 \leq p_r (q_2 \leq q_r)\text{: } \textit{not predatory} \text{ (firm unconstrained, } v_r^A = v_2^A \geq v_1^A) \end{aligned} \tag{4.3}$$

Intuitively, for all cases where firm $A$'s new monopoly (and equilibrium) price is below the test level ($p_2 \leq p_r$), the test outputs $(q_h^A, q_h^B)$ will coincide with the actual new equilibrium outputs $(q_2^m, 0)$. Since $V_2^A(q_2^m, 0) \geq v_1^A$ is required for the investment to be undertaken, the test finding will be "not predatory." In the other cases ($p_2 > p_r$), firm $A$'s profit for test purposes is $v_r^A$ and the finding is *predatory* $\Leftrightarrow (v_r^A - v_1^A) < 0$. Inspecting (4.2), where $(v_r^A - v_1^A)$ is but one term, one suspects that the testing finding will not perfectly track the change in welfare. Indeed, using decomposition (4.2) and the model of Section 2 under Cournot interaction, Appendix 2 (available on request) constructs examples of exit-inducing investments for which versions (a) and (b) of the test commit various types of errors. It is useful to outline these errors.

Version (a), $p_r = p_1$, finds *not predatory* some welfare-decreasing investments (Type II error), whether equilibrium price rises or falls. This is not surprising, since all investments that reduce equilibrium price are found



not predatory in this version of the test and we know from Remark 5 part (iii) that there are price-reducing investments that both induce exit and reduce welfare. (Showing that there are investments that increase price and reduce welfare yet are found "not predatory" is also straightforward.) Somewhat more surprising is that this version of the test finds "predatory" some investments that increase welfare (Type I error). That is, there exist investments that induce exit and raise equilibrium price but increase welfare—even though the investments are profitable only because price rises (in order to be found "predatory" by this version of the test).[12]

Version (b) of the test, $p_r = \min AC^B$, also generates both Type I and Type II errors. The Type I error arises because there are investments that would be unprofitable if the firm were forced to reduce price all the way below the rival's average cost but would be profitable and increase welfare absent this constraint, e.g., if the rival's initial profit were negligible and equilibrium price fell or even rose slightly. Now consider Type II error. A finding of "not predatory" here means that the investment would be profitable even if price were kept at (or below) the rival's minimum average cost. If price were in fact kept there, all such investments (i.e., those found "not predatory") obviously would increase welfare—the rival's loss would be outweighed by consumers' gain. However, for some such investments firm $A$ raises price above min $AC^B$ in the actual monopoly equilibrium, hence welfare can fall (Type II error).

*Remark* 6

Any rule of the kind in (4.1) with $q_h^B = 0$ is welfare dominated by a rule that permits all exit-inducing investments but prevents the investing firm from then raising price above the level $p_r = P(q_r)$.

The reason is straightforward. Tests in (4.1) with $q_h^B = 0$ acquit only investments that would be profitable at $p \leq p_r$; so clearly none of these would be discouraged by the alternative rule. And by requiring that price actually not be raised above $p_r$, something OW-type tests do *not* require, welfare can only be improved. Observe also that the alternative rules absolve the policymaker from knowing the investor's initial profit $v_1^A$ and new profit function $V_2^A$. Of course, they involve the standard problems associated with price regulation, such as preventing shading of quality.

Ordover and Willig showed that their test is perfect—but under highly restrictive assumptions: (a) constant and identical average costs, (b)

[12] Since any profit gained due to a price increase constitutes a transfer from consumers, an investment whose profitability hinges on raising price might be expected to reduce welfare. This logic breaks down, however, if the investing firm's new marginal cost is increasing. The investment could then prove unprofitable if the firm were forced to supply the entire initial industry output; yet it could increase welfare, despite reducing industry output, by sufficiently lowering the industry's cost of the new output. The latter can occur if the rival firm had lower marginal cost than the investor but a larger recoverable fixed cost. See Appendix 2 (available on request).

price-taking behaviour and (c) vertical demand (OW pp. 24–25).[13] OW acknowledge that this environment has no initial distortions (OW p. 50, n. 90) and conjecture, as does Scheffman (1981), that the test will not achieve optimality under more general conditions. They nevertheless characterize their test as "economically sound, judicially workable, and broadly applicable to a wide variety of business practices" (OW, p. 8). Since initial distortions and second-best comparisons are the norm in antitrust, OW's position is not convincing. I have identified situations where their test is too restrictive and others where it is too permissive, and offered a superior rule.

## 5. Conclusion

This paper examines the welfare effects of "investments", actions that involve one firm reducing its marginal cost through spending a fixed cost (possibly zero). A major objective is to clarify why welfare can fall even if industry price is lowered and even if the investment entails zero fixed cost, namely, because of inefficient reshuffling of output from the rival to the investing firm. A horizontal merger that leads to a reduction in the merging firms' marginal costs but includes only a subset of industry members can create similar output reshuffling and corresponding welfare ambiguities, even if price falls.

What this implies for policy is a more delicate question. The underlying premise of this paper is that a firm is likely to have reasonably accurate information about the likely effects of its actions, so that by penalizing investments found to decrease welfare it might be possible to induce firms to forego such investments. A strong case can be made that the danger of convicting the innocent is sufficiently great to justify a laissez-faire approach. However, a consensus on this point is not imminent and some antitrust scrutiny of investments will probably continue, at least when allegations of predation arise in highly concentrated markets.

Ordover and Willig propose a test for whether an investment is predatory. Their test relies on an intuitively appealing and commonly held notion of what constitutes predatory behaviour. I formulate their test in a general way that admits various interpretations, show why errors will occur under any of these, and describe the errors for two specific interpretations. I also identify superior price-regulation rules. While the drawbacks of price regulation—notably how to cope with changing costs and demand and prevent quality shading—might well be prohibitive, this would still not support the adoption of an Ordover–Willig type test (whatever the particular version). Implementing such a test requires an enormous amount

[13] Under these assumptions, $p_1 = \min AC^B$ so the test prices of versions (a) and (b) coincide. It is easy to see why the test is then perfect. The rival's profit is zero, so any price-reducing investment will be found not predatory and will increase welfare. Some price-increasing investments also will be found not predatory; ordinarily such investments can reduce welfare, but OW's vertical demand assumption precludes this.



of information. If such information were available, it could be used instead to estimate fairly accurately the welfare change and avoid some of the errors that the test generates.

In practice, the information available to policymakers will be quite limited, even ex post. With this in mind, I show how observables, such as prices and outputs, could provide some guidance about the change in welfare. Further work along these lines, using richer models, is sorely needed.

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## APPENDIX 1: COURNOT EXAMPLES

This Appendix specializes the general model of Section 2 to Cournot duopoly interaction between firms $A$ and $B$ with linear demand and constant but different marginal costs. I first consider cases where the rival stays in, thereby proving Remark 4 and the welfare ambiguity part of part (ii). Next I consider cases where the rival exits, proving Remark 5, part (iii) and establishing a result used in proving Proposition 1.

Let inverse demand be $p = a - q$. Denote the first-period marginal costs by $c_1^A$ and $c^B$, and second-period marginal cost by $c_2^A < c_1^A$ and $c^B$. Thus, $\Delta c^A = c_2^A - c_1^A < 0$. Recall that there are recoverable fixed costs, $g^A$ and $g^B \geq 0$ and that $A$ incurs a fixed cost $f \geq 0$ to achieve $c_2^A$. Denote gross profit by $\pi^i = (p - c^i)q^i$, $i = A, B$. Firm $i$'s net profit is therefore $\pi^i$ less any fixed cost(s). The following Cournot-equilibrium expressions will prove useful:

$$q^i = \frac{a - 2c^i + c^j}{3}, \qquad p = \frac{a + c^i + c^j}{3}, \qquad \pi^i = (q^i)^2 \tag{A.1}$$

$$\Delta q^A = -2\Delta q^B = 2\Delta q \quad \text{where} \quad \Delta q = -\frac{\Delta c^A}{3} = \frac{c_1^A - c_2^A}{3} \tag{A.2}$$

$$\Delta\pi^i = (q_2^i)^2 - (q_1^i)^2 = \Delta q^i(2q_1^i + \Delta q^i) \tag{A.3}$$

Note that the expressions are valid only for $q^i \geq 0$, i.e., for $c^i \leq (a + c^j)/2$. Finally, the change in consumer surplus is

$$\Delta s = \Delta q(q_1^A + q_1^B + \Delta q/2) \tag{A.4}$$

### A. *Rival stays in the market*

Firm $B$ stays in the market if $\pi_2^B > g^B$, which will be met in our examples. Using (A.2), the welfare-change expression (3.6) simplifies to

$$\Delta w = \Delta q(\Delta q/2 + p_2 - c_2^A) + (c_1^A - c_2^A)q_1^A - (c_2^A - c^B)\Delta q - f. \tag{A.5}$$

Obtaining $\Delta w > 0$ is obviously possible. For example, assume $c_2^A = c^B$ and $f = 0$.

It is more interesting to consider welfare-decreasing investments. I examine the two extreme cases: $f = 0$ and $f = \Delta\pi^A$; the latter is the maximum value of $f$ consistent with firm $A$'s choosing to invest. In (A.5) $\partial\Delta w/\partial q_1^A > 0$, so to minimize $\Delta w$ (maximize the loss) I assume throughout that $q_1^A = 0$. (Assuming $q_1^A = 0$ rather than positive but "small" is done purely for convenience. To obtain $q_1^A = 0$ while retaining the validity of the Cournot output expressions in (A.1), assume $c_1^A = (a + c^B)/2$.)

To contrast the case $f = 0$ with that of $f = \Delta\pi^A$, it is convenient to express $\Delta w$ in terms of $\Delta\pi^A$, $\Delta\pi^B$ and $\Delta s$. Using (A.2), (A.3) and (A.4) and substituting $q_1^A = 0$ gives

$$\Delta\pi^A = (2\Delta q)^2, \qquad \Delta\pi^B = \Delta q(\Delta q - 2q_1^B), \qquad \Delta s = \Delta q(\Delta q/2 + q_1^B). \tag{A.6}$$

For $f = 0$, $\Delta w = \Delta\pi^A + \Delta\pi^B + \Delta s$. Therefore,

$$\Delta w = \Delta q(11\Delta q/2 - q_1^B) \quad \text{if } f = 0. \tag{A.7}$$

For $f = \Delta\pi^A$ we have $\Delta w = \Delta\pi^B + \Delta s$. Again using (A.6) gives

$$\Delta w = \Delta q(3\Delta q/2 - q_1^B) \quad \text{if } f = \Delta\pi^A. \tag{A.7'}$$

Both (A.7) and (A.7′) are quadratics which can be solved for $\Delta q$ in terms of $q_1^B$. There is an implied relation between the underlying parameters since $\Delta q = (a + c^B - 2c_2^A)/6$ and $q_1^B = (a - c^B)/2$. (Substitute into (A.2) and (A.1) $c_1^A = (a + c^B)/2$, assumed in generating $q_1^A = 0$.) The following table shows where $\Delta w \leq 0$ and where $\Delta w$ is minimized.

TABLE 1
*Cost values for which Welfare Falls*

| Investment's cost | $\Delta w < 0$ | $\Delta w$ at minimum |
|---|---|---|
| costless: $f = 0$ | $c_2^A \geq c^B + 5(a - c^B)/22$ ($\Delta q \leq q_1^B/11$) | $c_2^A = c^B + 8(a - c^B)/22$ ($\Delta q = 2q_1^B/11$) |
| most costly: $f = \Delta\pi^A$ | $c_2^A \geq c^B - (a - c^B)/2$ ($\Delta q \leq 2q_1^B/3$) | $c_2^A = c^B$ ($\Delta q = q_1^B/3$) |

Note that $c_2^A \geq c^B$ ensures a welfare gain for costless investments but not for the costly ones. In fact, the latter exhibit greatest welfare loss if $c_2^A = c^B$. In these examples, the maximum losses are −6.7 per cent ($f = 0$) and −15.8 per cent ($f = \Delta v^A$) of initial welfare.

These magnitudes are computed as follows. Substituting $\Delta q = q_1^B/11$ into (A.7) gives $\Delta w = -(q_1^B)^2/22$. Substituting $\Delta q = q_1^B/3$ into (A.7′) gives $\Delta w = -(q_1^B)^2/6$. The maximum feasible value of $q_1^B$ is $a/2$ (occurring for $c^B = 0$, $c_1^A = a/2$). Substituting, gives $\min \Delta w = -a^2/88$ for $f = 0$, $\min \Delta w = -a^2/24$ for $f = \Delta\pi^A$. To calculate the proportional changes, $\Delta w/w_1$, note that in our examples $\pi_1^A = 0$ so $w_1 = \pi_1^B - g^B + s_1 = (a/2)^2 - g^B + (a/2)^2/2 = 3a^2/8 - g^B$. The highest value of $g^B$ consistent with firm $B$ staying in the market is $g^B = \pi_2^B$. For the case $f = 0$ above, $\pi_2^B = (q_2^A)^2 = a^2(\frac{5}{11})^2$, using (A.1) and substituting $c_2^A = 4a/11$, $c^B = 0$. Then $w_1 = a^2(\frac{3}{8} - \frac{25}{121})$ implying $\Delta w/w_1$ of approximately −6.7 per cent. For the case $f = \Delta\pi^A$ above, $\pi_2^B = a^2/9$ hence $w_1 = a^2(\frac{3}{8} - \frac{1}{9}) = 19a^2/72$. Since $\Delta w = a^2/24$ $\Delta w/w_1 = -3a^2/19$ or approximately −15.8 per cent.

B. *Rival exits*

Consider an initially symmetric equilibrium, $c_1^A = c_1^B = c$. Using (A.1),

$$q_1^i = (a - c)/3, \qquad p_1 = (a + 2c)/3, \qquad \pi_1^i = (a - c)^2/9, \qquad i = A, B. \tag{A.8}$$

After $A$'s investment, marginal costs are $c_2^B = c$, $c_2^A < c$. If firm $B$ exits, the new equilibrium has firm $A$ as a monopolist:

$$q_2 = q_2^A = (a - c_2^A)/2, \qquad p_2 = (a + c_2^A)/2, \qquad \pi_2^A = (q_2^A)^2/4. \tag{A.9}$$

Firm $A$ invests if

$$\Delta\pi^A = \pi_2^A - \pi_1^A \geq f \tag{A.10}$$



and firm $B$ exits if its new Cournot profit, $\bar{\pi}_2^B$, would not exceed its fixed cost $g^B$, where $\bar{\pi}_2^B = (\bar{q}_2^B)^2 = (a - 2c + c_2^A)^2/9$ by (A.1). Since $B$ is active initially, $g^B < \pi_1^B$. Therefore $\bar{\pi}_2^B \leq g^B < \pi_1^B$ hence

$$0 < \pi_1^B - g^B \leq \pi_1^B - \bar{\pi}_2^B \quad \text{where} \quad \pi_1^B - \bar{\pi}_2^B = [(a - c)^2 - (a - 2c + c_2^A)^2]/9. \tag{A.11}$$

Changes in price, welfare, and consumer surplus are:

$$\Delta p = (a + 3c_2^A - 4c)/6 \tag{A.12}$$

$$\Delta w = (\Delta\pi^A - f) - (\pi_1^B - g^B) + \Delta s \tag{A.13}$$

$$\Delta s = q_2^2/2 - q_1^2/2 = (a - c_2^A)^2/8 - 2(a - c)^2/9. \tag{A.14}$$

In order to prove Proposition 1 part (iii), we must find different parameter values $(a, c, c_2^A, f, g^B)$ satisfying (A.10) and (A.11) and yielding the four combinations of $\Delta p$ and $\Delta w$. Purely for convenience, we choose values for $(a, c, c_2^A)$ that yield arbitrarily small $\Delta p$, hence arbitrarily small $\Delta s$, so that $\Delta w$ is driven by changes in profits. Let $c_2^A = 0$. Then $q_2^A = a/2$, $\pi_2^A = a^2/4$, $p_2 = a/2$, $\Delta p = (a - 4c)/6$. Thus $\Delta p \gtreqless 0$ as $c \lesseqgtr a/4$. The four combinations of $\Delta p$, $\Delta w$ are shown below, where $\varepsilon > 0$ but arbitrarily small.

TABLE 2
*Price and Welfare Changes from Exit-Inducing Investments*

| $\Delta p > 0,\ \Delta w > 0$ | $\Delta p > 0,\ \Delta w < 0$ | $\Delta p < 0,\ \Delta w > 0$ | $\Delta p < 0,\ \Delta w < 0$ |
|---|---|---|---|
| $c = a/4 - \varepsilon$ | $a/4 - \varepsilon$ | $a/4 + \varepsilon$ | $a/4 + \varepsilon$ |
| $f = 0$ | $\Delta\pi^A$ | 0 | $\Delta\pi^A$ |
| $g^B = \pi_1^B - \varepsilon$ | $\bar{\pi}_2^B$ | $\pi_1^B - \varepsilon$ | $\bar{\pi}_2^B$ |
| $\Delta w \cong \Delta\pi^A$ | $-(\pi_1^B - \bar{\pi}_2^B)$ | $\Delta\pi^A$ | $-(\pi_1^B - \bar{\pi}_2^B)$ |

To get a sense for the magnitudes, consider the case $\Delta p < 0$, $\Delta w < 0$. Substituting $c = a/4 + \varepsilon$ gives $\Delta w \cong -(\pi_1^B - \bar{\pi}_2^B) = -5a^2/144$. Assuming $g^A = g^B$, $w_1 = s_1 + 2(\pi_1^B - g^B) = q_1^2/2 + 2(\pi_1^B - \bar{\pi}_2^B) = 14a^2/72$. Therefore $\Delta w/w_1 = -\frac{5}{28}$ or −17.9 per cent.

Finally, to complete the step used in proving Proposition 1, we construct cases such that: $\Delta\pi^A = f$; firm $B$ exits; and the sign of $\Delta w$ hinges on the value of $g^B$. Given the parameters influencing $\Delta\pi^A$, choose $f = \Delta v^A$. Then $\Delta w = \Delta s - (\pi_1^B - g^B)$ implying, by (A.11), that $\Delta w \in [\Delta s - (\pi_1^B - \bar{\pi}_2^B), \Delta s)$. Retain the assumptions of the earlier example, $c_1^A = c_1^B = c$ and $c_1^A = 0$. Substituting in (A.11) and (A.14) gives $\pi_1^B - \bar{\pi}_2^B = (a - c)^2/9 - (a - 2c)^2/9$ and $\Delta s = a^2/8 - 2(a - c)^2/9$. Therefore $\Delta s - (\pi_1^B - \bar{\pi}_2^B) = [8c^2 + 16ac - 7a^2]/72$. This is a quadratic taking negative values for $c/a < [(30)^{0.5} - 4]/4$ or approximately 0.37. And $\Delta s > 0$ for $c/a > 0.25$. Therefore, for $0.25 < c/a < 0.37$, $\Delta w >$ or $< 0$ depending on $g^B$.

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