Decentralization, Transfer Pricing and Tacit Collusion

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Abstract

Research in accounting traditionally regards transfer pricing as an intra-firm transaction problem. Within the context of a simple Cournot model, we demonstrate that firms can use transfer prices strategically as a collusive device. While firms are individually better off from a centralized organizational form with each internal division transferring intermediate goods at marginal cost, all firms benefit from a collusive agreement to organize along profit centers, transferring goods above marginal cost. This collusion yields roughly twice the competitive profits and is sustainable even when price or quantity collusion is not. This practice may also escape legal scrutiny while the same cost-shifting between regulated monopolists and their corporate affiliates is regarded as a major concern for regulators and researchers.

Keywords: transfer pricing, collusion, strategic delegation, vertical integration

1 Introduction

Research in accounting traditionally regards transfer pricing as an intra-firm solution to issues such as information asymmetries between corporate authority and divisional managers or tax minimization for multi-national firms facing different tax rates.[1] In the absence of these complications, transfer prices are deemed to serve little purpose as optimality is achieved by transferring goods to the buying division at the marginal cost of the selling division (Hirshleifer, 1956). Yet, only about half of American firms use any form of cost-based transfer pricing, a category which includes the economically inefficient system of transferring at full (including fixed) cost (Cheng, 2002; Eccles and White, 1988). This paper offers an alternative perspective on the setting of transfer prices which may explain transfers above marginal costs even in perfect-information, tax-free environments. We demonstrate how transfer prices can be used as a strategic tool to achieve tacit collusion among competing firms, leading to higher profit for all participants.

Although transfer prices govern trade within a firm, they may also impact the competitive environment in which the firm operates. The structure of transfer prices often affects the final prices firms offer to end markets, and hence its competitors in those markets. A firm with two divisions that operate in two different markets can strategically allocate costs between the divisions through transfer prices to alter behavior of its rivals (Bulow, Geanakoplos and Klemperer, 1985; Gal-Or, 1993; Alles and Datar, 1998; Hughes and Kao, 1998). This kind of cost-shifting or cross-subsidization is a prominent phenomenon in industries ranging from health care (Foreman, Keeler and Banks, 1999) and insurance markets (Puelz and Snow, 1994) to professional sports (Fort and Quirk, 1995), but is especially a concern in regulated industries. A regulated firm can purposefully have its unregulated affiliate overcharge the parent firm to inflate the parent firm's cost and final price to consumers. Meanwhile, the unregulated affiliate can also afford to adopt predatory prices to deter new entrants into the market. Contributing to the break-up of AT&T were accusations of its adopting unreasonably high transfer prices from Western Electric, one of its unregulated subsidiaries, to support higher rates on local telephone services.

These regulated firms are strategically employing double marginalization, which has been cause for concern for both researchers (e.g., Brennan, 1990) and regulators. To avoid this consequence, regulators often provide specific guidelines on the pricing of internal transactions between regulated parents and affiliates enforced through frequent audits.

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[1] Recent examples include Edlin and Reichelstein (1995), Vaysman (1996), Baldenius (2000), Baldenius and Reichelstein (2006), and Baldenius, Reichelstein and Sahay (1999), for informational asymmetry; and Jacob (1996), Klassen, Lang and Wolfson (1993), Harris (1993), and Smith (2002), for tax rates.

Examples can be easily found in industries such as public utilities or telecommunication.[2]

This phenomenon is not limited to regulated industries. In this study, we investigate how transfer prices can be used as a strategic tool for competing firms to achieve tacit collusion. In our model, firms do not face information asymmetries, agency costs, or tax consequences, removing several traditional motivations for transfer prices. We consider the role of internal transfer prices within the context of a Cournot model of competition.

Each firm consists of an upstream division, the internal supplier, and a downstream division that takes the inputs from the supplier and sells to the market. The price at which internal transfers occur depends on the organizational form adopted by the firm. Firms can adopt one of two organizational forms. A centralized firm determines all inter-divisional transactions based on overall corporate profit maximization. A decentralized firm treats its divisions as independent profit centers, allowing each to set prices and quantities based on divisional profit-maximization concerns. A centralized firm will set its transfer price at the marginal cost of the upstream division while the decentralized firm will allow its upstream division to charge a transfer price that maximizes its divisional profit.

We first confirm the fundamental principle that each firm is not only better off if divisions are compelled to transfer at marginal cost, but also that such centralized control is a dominant strategy. It is optimal to adopt a centralized organizational form regardless of the organizational governance adopted by others in the industry. However, we show that all firms are better off if each decentralizes decision-making and operates independent profit centers. If divisions in competing firms are run as profit centers, successive divisions mark up prices, serving to inflate input costs to the downstream division and resulting in artificially higher prices. When such organizational forms are adopted by all firms, we show that industry-wide profits are roughly double those obtained at the noncooperative equilibrium. An n-person prisoner's dilemma results; while each firm has the incentive to establish a centralized structure, all are benefited if each operates independent profit centers. Thus, profit centers may be used to facilitate collusion, and such collusion is shown to be sustainable even when collusion on price or quantity would not be possible. Further, while the collusive scheme distorts away from efficiency, it may drive total industry output even below the monopoly output.

Our results have an intuitive explanation. The goal of collusion is to raise prices closer to monopoly levels. Allowing upstream divisions to set profit-maximizing prices for their

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[2] For example, the Public Utility Commission of Texas has noted that: "[T]here is a strong likelihood that a utility will favor its affiliates where these affiliates are providing services in competition with other, non-affiliated entities . . . there is a strong incentive for regulated utilities or their holding companies to subsidize their competitive activity with revenues or intangible benefits derived from their regulated monopoly businesses" (Public Utility Commission of Texas, 1998).

input goods inflates the effective cost for downstream divisions, resulting in just such higher prices. All firms in the industry enjoy the "double-marginalized" profits.

Compared to traditional models of collusion on price or quantity, colluding on organizational form yields several advantages for firms. The first advantage concerns the sustainability of collusion on organizational form. With traditional price and quantity collusion, the set of discount rates which support collusion vanishes as the number of firms becomes large. Asymptotically, price and quantity collusion both require interest rates arbitrarily close to zero for collusion to be sustainable even under the most rash (grim trigger strategy) punishments by other firms. Conversely, the enforcement of collusion on organizational form is substantially simpler. We show that collusion on organizational form is sustainable for a wide range of interest rates and, even as the number of firms becomes arbitrarily large, interest rates as high as 50% still allow collusion to be sustained.

A second advantage of colluding on organizational form concerns enforcement. Agreeing to set prices or quantities is *per se* illegal, while the selection of organizational form is not only less regulated but is commonly discussed at industry conferences without raising antitrust concerns. Thus, it facilitates tacit collusion, in which seemingly unilateral, noncoordinated actions serve to enforce artificially high prices. In fact, we may conjecture that colluding on transfer pricing through organizational structure is the most profitable form of collusion within legal limits.

Industry studies suggest that oligopolists tend to converge in their business models, strategies, and organizational structures. Pepsi and Coca Cola both steadily integrated with their bottling suppliers (Saltzman, Levy and Hilke, 1999). Major car makers spun off component suppliers both in the United States (Lin, 2006) and Japan (Ito, 1995). Grocers and retailers established their own distribution centers (Martinez, 2002). Television networks increasingly produce their own shows (Einstein, 2004). Changes to organizational form are usually observable by competitors, facilitating tacit coordination and convergence.

A concern after the break-up of AT&T was the possible collusion among the regional Bell operating companies through common agreement to inflate transfer prices (Shughart, II, 1995). If they all agreed not to offer inputs at competitive prices or to report similarly inflated costs, they could sustain the cross-subsidies in which AT&T was previously engaged. Our model addresses precisely this issue.

In contrast to most of the transfer pricing literature envisioning transfer prices as solving an imperfection within a firm, this paper is among a few studies (Bulow, Geanakoplos and Klemperer, 1985; Gal-Or, 1993; Alles and Datar, 1998; Hughes and Kao, 1998) that examine the strategic role of transfer pricing, though their focus and conclusions are quite different from ours. This paper also relates to several recent papers in economics that compare centralized and decentralized corporate structures, including those by Baron and Besanko (1992), Moorthy (1988), Melumad, Mookherjee and Reichelstein (1992), and Laffont and Martimort (1998). The conception of the firm in this paper is substantially simpler, deliberately ignoring issues like commitment and renegotiation ability. However, the possibility of collusion *among* firms is explicitly modeled. Laffont and Martimort (1998) consider collusion among divisions *within* a firm. Bonanno and Vickers (1988) establish that vertical separation can increase profit within the context of a Bertrand duopoly. None of these studies examines the sustainability of collusion.

Some authors have specifically noted the strategic role of decentralization and delegation (Sklivas, 1987; Fershtman and Judd, 1987; Alles and Datar, 1998). A manager may be compensated partly based on sales (Basu, 1995) or market share (Wauthy, 1998), which serves as a commitment to higher output, resulting in competing firms decreasing output. In contrast to the present study, these approaches are adopted by all firms in equilibrium and result in lower profits.[3]

2 Model

Each of n firms is composed of two divisions. The upstream division costlessly produces an intermediate good which the downstream division converts into a final consumer good using a 1:1 Leontief production technology. That is, the input is the only requirement for production, and each unit of the input good is transformed into a single unit of the final good. Note that we are assuming that there is no external market for these goods; the upstream division is the only seller and the downstream division is the only buyer within each firm. We consider the role of an external market in a later section. We distinguish between two types of organizational forms: decentralized, in which each division maximizes its profit, and centralized, in which a central planner requires the transfer of goods from the upstream to the downstream division at cost. Thus, the downstream division's marginal cost is precisely the price charged by the upstream division for the intermediate good. The downstream divisions compete in quantities, *a la* Cournot. Downstream demand is given by the familiar linear form:

$$p_i = a - bq_i - bQ_{-i} \tag{1}$$

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[3] Fershtman, Judd and Kalai (1991) demonstrate that the collusive outcome is obtainable in equilibrium when a manager is offered an incentive contract that pays a positive amount only if the profit obtained is near the collusive profit and if a manager can base his quantity on the contract offered.

where $Q_{-i} = \sum_{j \neq i} q_j$ is the output of all of firm i's competitors. The timing of the game proceeds as follows:

1. Firms simultaneously select an organizational form, $o_i \in \{C, D\}$, either centralized or decentralized.
2. Upstream divisions of decentralized firms set a transfer price, t_i, to maximize division profit. Centralized firms transfer at marginal cost, assumed to be 0.
3. Downstream divisions select quantities to maximize profit.

In the following subsection, we derive the equilibrium of this game and demonstrate that the selection of a centralized organizational structure is a dominant strategy.

2.1 Non-Cooperative Equilibrium

We identify the unique subgame perfect equilibrium. As is customary, we analyze the game backwards, first solving the downstream division's optimization problem given any profile of transfer prices elected by the upstream divisions. Given input costs of t_i, the maximization problem faced by the downstream division at firm i is

$$\max_{q_i} \; (a - bq_i - bQ_{-i} - t_i)q_i \tag{2}$$

which yields, for each firm, the first order conditions

$$q_i = \frac{a - t_i}{2b} - \frac{1}{2}Q_{-i} \tag{3}$$

which generate the equilibrium quantities:

$$q_i^*(t_i, T_{-i}) = \frac{(a - nt_i + T_{-i})}{(n+1)b} \tag{4}$$

where $T_{-i} = \sum_{j \neq i} t_j$. Since the transfer prices are set by the upstream divisions of decentralized firms, the above equation is an implied demand curve for these divisions. Hence, the upstream division in a decentralized firm solves

$$\max_{t_i} \; t_i q_i^*(t_i, T_{-i}) \tag{5}$$

while a centralized firm transfers at marginal cost, assumed to be 0.

Assume that m firms have decentralized organizational forms and $n-m$ firms transfer at marginal cost. Then, solving (5) results in transfer prices given by

$$t_i = \begin{cases} \frac{a}{2n-m+1} & o_i = D \\ 0 & o_i = C \end{cases} \tag{6}$$

with resulting quantities,

$$q_i = \begin{cases} \frac{an}{(n+1)(2n-m+1)b} & o_i = D \\ \frac{a(2n+1)}{(n+1)(2n-m+1)b} & o_i = C \end{cases} \tag{7}$$

Proposition 1. *$o_i = C$ is a dominant strategy.*
A centralized firm (transferring at marginal cost) always earns strictly greater profits than a decentralized firm for any election of organizational form by its competitors.

The proof of this and all other results is in the appendix. This confirms Hirshleifer's (1956) result that it is preferable to transfer goods at marginal cost, regardless of the behavior of the rest of the industry. The equilibrium is:

$$o_i = C, \quad t_i = 0, \quad q_i = \frac{a}{(n+1)b} \quad \forall i$$

with resulting industry price and profits of $p^{eq} = \frac{a}{n+1}$ and $\Pi_i^{eq} = \frac{a^2}{(n+1)^2 b}$ which are the familiar results of a Cournot model with linear demand and zero marginal costs.

3 Collusion

Next, consider the outcome if firms collude on organizational form. If all firms adopt a decentralized structure despite the strong inclination to centralize, greater profits result.

Proposition 2. *Colluding on organizational form is profitable.*
If all firms set $o_i = D$, the resulting collusive profit exceeds equilibrium profit.

A natural question is how sizeable is the increase in profit? Does collusion result in only marginal increases, especially as the number of firms gets large, or in marked profit improvements? The next remark addresses this issue. Let Π_i^{col} denote the profit of a representative firm when all firms adopt the decentralized organizational form ($o_i = D \ \forall i$).

Remark 2.1. *As $n \to \infty$, $\frac{\Pi_i^{col}}{\Pi_i^{eq}} \to 2$.*

The increase in profits appears not to be trivial and, for large n, profits are roughly doubled. The smallest relative profit increase brought about by a conspiracy is when $n = 2$. However, the efficiency impact of collusion with only two firms is stark.

Remark 2.2. *For $n = 2$, collusion on organizational form is less efficient than a monopoly.*

Hence, when $n = 2$, firms colluding on organizational form earn lower profits than if they colluded purely on price or quantity, but do so at the expense of efficiency. By restricting output below monopoly levels, this suggests that a merger from two firms to one may actually increase efficiency. The benefits accrued from eliminating the intentional double-marginalization present in each of the two firms outweighs the loss of competition.

4 Sustainability

In the previous section, we found that each firm has a dominant strategy, and that if each firm elects instead to play its dominated strategy, the profits of all firms are improved. Firms find themselves playing an n-player prisoner's dilemma. Each firm earns a greater profit from centralizing than from the equilibrium (decentralized) outcome. However, since decentralization is a dominant strategy, the incentive to cheat on the equilibrium agreement is ever-present. In this section, we consider the sustainability of cooperation when accompanied by sufficient threats to revert to noncooperative play. Specifically, it is assumed that each firm credibly commits to using the grim trigger strategy. Trigger strategies, in general, imply that all firms will play cooperatively until any firm cheats. Then, in the continuation game, all firms will play non-cooperatively and thus the Nash equilibrium will obtain*ad infinatum.*[4] Letting $\delta = \frac{1}{1+r}$ denote the discount rate where r is the interest rate, and letting Π^{eq}, Π^{col}, and Π^{ch} be the equilibrium, collusive, and cheating profits, respectively, collusion is sustainable if the present value of collusion is greater than the present value of cheating enforced by the grim trigger strategy :

$$\begin{aligned} \tfrac{1}{1-\delta}\Pi^{col} &> \Pi^{ch} + \frac{\delta}{1-\delta}\Pi^{eq} \\ \equiv \qquad \delta &> \frac{\Pi^{ch} - \Pi^{col}}{\Pi^{ch} - \Pi^{eq}} \end{aligned} \tag{8}$$

Denote the δ that satisfies (8) with equality as δ^*. This represents the minimum sustainable discount rate. Further, we distinguish between three forms of collusion: price, quantity, and organizational form collusion, and refer to their minimum sustainable discount rates as $\delta^{*(p)}, \delta^{*(q)}$, and $\delta^{*(o)}$, respectively.

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[4] The grim trigger strategy is used to obtain the minimum sustainable discount rate and thus requires a maximal credible punishment (Friedman, 1971). Alternatives to trigger strategies in environments with uncertainty are provided by Green and Porter (1984) and Abreu (1986). Whether the threat of permanent reversion to the noncooperative equilibrium is credible is not explicitly considered.

A traditional result in price and quantity collusion is that sustainability becomes more difficult with more firms, and no reasonable interest rate may sustain collusion as the number of firms becomes large.

Proposition 3. *As* $n \to \infty$*,* $\delta^{*(p)} \to 1$*, and* $\delta^{*(q)} \to 1$*.*

The above implies that as the number of firms becomes large, collusion is only sustainable if future profits are as valuable as present profits—if no discounting occurs. Hence, even under the most drastic of punishments, the grim trigger strategy, neither price nor quantity collusion is sustainable asymptotically. Collusion on organizational form is far easier to support, however.[5]

Proposition 4. *(i)* $\delta^{*(o)} < 1$ *and (ii)* $\delta^{*(o)} < \frac{2}{3}$ *for* $n \geq 4$*.*

Even as the number of colluding firms becomes large, the critical discount rate is bounded by 2/3, implying that collusion is feasible, using the grim trigger strategy, when the interest rate is below 1/2. The intuition for this result lies in the lower profits obtainable by cheating. In all three types of collusion considered here (price, quantity, and organizational form), both equilibrium and collusion profits go to zero as the number of firms becomes large. However, with price and quantity collusion, the profits from cheating remain bounded away from zero. In price collusion, for example, a cheating firm appropriates the entire monopoly profit by slightly undercutting the agreed upon price, capturing the entire market. When colluding on organizational form, conversely, cheating does result in greater profits than does colluding, but the gains from cheating also vanish as the number of firms approaches infinity.

5 An External Market

In the previous sections, we derived results in the absence of an external market for the intermediate goods produced by upstream divisions. In this section, we briefly consider the role such a market would play and confirm that our results still obtain, qualitatively.

Holding everything else the same as in the previous sections, we now introduce an external market for the intermediate good produced by the upstream divisions. The market is composed of firms' upstream divisions from the seller side and firms' downstream divisions from the buyer side. We assume a centralized firm avoids the external market and transfers from its upstream to its downstream division internally. A decentralized firm has its upstream division competitively selling the intermediate good to an external

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[5] Note that result for $\delta^{*(p)}$ is not directly comparable to our model since we presume Cournot (quantity) competition among downstream divisions, but is provided for completeness.

market, competing against other upstream divisions of decentralized firms. Compared to the previous section, a second level of Cournot competition is created; first, intermediate goods are sold among decentralized firms, and second, final goods are sold to the market by all firms.

Consider the case where all firms are decentralized. Since competition among the upstream divisions implies a single, market-clearing price in the intermediate-goods market, we have $t_i \equiv t$ for all i. From Equation 4, downstream quantities are given by:

$$q_i^*(t) = \frac{a-t}{(n+1)b} \tag{9}$$

for any intermediate-goods price, t. Solving for t and substituting total market quantity, we obtain the demand in the intermediate-goods market.

$$t = a - \left(\frac{n+1}{n}\right) bQ \tag{10}$$

Effectively, the market-clearing price in the intermediate-goods market becomes the input cost to downstream divisions. Thus, the demand faced by upstream divisions is the residual demand of the downstream divisions.

Proposition 5. *Equilibrium profits and collusive profits in the presence of an external market are equivalent to those in the absence of an external market.*

In equilibrium, all firms are centralized. Since no firm avails itself of the external market, this is identical to our earlier results. In the case of a collusive market, all firms have their upstream divisions selling to the intermediate goods market. Unlike the previous section, in which each upstream division is effectively a sole seller to one of the n market participants, each becomes one of n sellers to the whole market in the presence of an external market. This result demonstrates that resulting firm profits are identical.

While the above proposition suggests that the gains from colluding on organizational form are invariant to the existence of an external market, the gains from cheating on this collusive scheme are not the same as when no external market exists.

Imagine that when a firm cheats, it stops selling to the external market and production decisions are made centrally (which is equivalent to assuming that the upstream division is supplied at marginal cost). Competitors continue to function in the external market for the remainder of that period (all later periods revert to equilibrium as per the grim trigger strategy) with full knowledge that the cheater will have a cost advantage. We define “cheating” in this setting as a firm centralizing its transfer pricing decisions and letting its upstream division sell the intermediate product to its own downstream division at desired quantity and marginal cost. This implies that the firm completely withdraws its production from the market. Having observed the "cheating" firm's action, other firms in the industry continue to function in the external market for the remainder of that period. We maintain the harshest (grim trigger strategy) punishment; other firms revert to equilibrium by centralizing in all later periods. [6] Again, we denote by $\delta^{*(o)}$ the minimum discount rate that sustains collusion.

Proposition 6. $\delta^{*(o)} < 1$ *for all* $n \geq 2$.

This result implies that collusion on organizational form is sustainable with or without an external market.

6 Conclusion

Double marginalization occurs when upstream divisions raise transfer prices without accounting for the resulting loss of profits in downstream divisions. In a competitive industry, the resulting final price leads to suboptimal overall profit of an individual firm as each markup is successively promulgated down the supply chain. However, all firms in an industry would benefit if they collude on inflating final prices to near-monopoly levels by artificially raising transfer prices.

We demonstrate that the seemingly unprofitable strategy of decentralizing price-setting decisions actually makes sense when considered in a strategic context, incorporating its impact on industry profitability. In particular, adopting inefficient organizational forms can serve as facilitating devices that make collusion sustainable when collusion on price or quantity would not be possible. We contribute to the literature by demonstrating how transfer prices can be used as a collusive mechanism to affect competition and thus welfare beyond one single firm. The results of the paper may also provide some explanation of why decentralization as an organizational form is becoming increasingly popular in many industries.

An intriguing question is how double marginalization in the context of this paper could escape scrutiny while the same type of cost-shifting between regulated monopolists and their corporate affiliates is regarded as a major concern for regulators and researchers. Price and quantity setting cartels have historically been considered antitrust violations *per se*, that is, without recourse to pro-competitive arguments. However, collusion on organizational structure is much easier to sustain as it has not generally triggered legal

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[6] Implicitly, we are assuming that a firm's exit from the external market is observed and allows the external market to reflect the equilibrium price among the remaining $n-1$ firms. Several other derivations under different informational assumptions yield similar qualitative results.

investigation. In fact, it is often encouraged by tax authorities around the world through "arms-length" standards which mirror the decentralized firms of our model. Encouraging firms to set transfer prices at market price levels may help facilitate tacit collusion.

7 Appendix

Proof of Proposition 1:: Substituting the equilibrium quantities in (7) into the demand equation (1), one obtains the industry price, given by

$$p = \frac{a(2n+1)}{(n+1)(2n-m+1)}$$

and profit is given by

$$\Pi_i = \{ \begin{array}{ll} \frac{a^2 n(2n+1)}{[(n+1)(2n-m+1)]^2 b} & o_i = D \\ \frac{a^2(2n+1)^2}{[(n+1)(2n-m+1)]^2 b} & o_i = C \end{array} \tag{11}$$

Consider the optimal response of firm i given that k firms have adopted decentralized organizational forms. If firm i adopts a decentralized form, then its profit (letting $m = k+1$) is $\frac{a^2 n(2n+1)}{[(n+1)(2n-k)]^2 b}$. If firm i elects to transfer at marginal cost, it earns $\frac{a^2(2n+1)^2}{[(n+1)(2n-k+1)]^2 b}$. To complete the proof, it is adequate to show that, for all $k \in \{1, ..., n-1\}$:

$$\begin{array}{rll} & \frac{a^2(2n+1)^2}{[(n+1)(2n-k+1)]^2 b} & > \frac{a^2 n(2n+1)}{[(n+1)(2n-k)]^2 b} \\ \equiv & (2n+1)(2n-k)^2 - n(2n-k+1)^2 & > 0 \end{array}$$

$$\begin{array}{rl} & \frac{a^2(2n+1)^2}{[(n+1)(2n-k+1)]^2 b} > \frac{a^2 n(2n+1)}{[(n+1)(2n-k)]^2 b} \\ \equiv & (2n+1)(2n-k)^2 - n(2n-k+1)^2 > 0 \end{array}$$

Since the left-hand side of the last expression is decreasing in k, one need only confirm it for $k = n-1$:

$$\begin{array}{rr} \equiv & (2n+1)(n+1)^2 - n(n+2)^2 > 0 \\ \equiv & n^3 + n^2 + 1 > 0 \end{array}$$

□

Proof of Proposition 2: If $o_i = D\ \forall i$, the profit-maximizing t_i derived by substituting $m = n$ into (6) is $\frac{a}{n+1}$. Substituting into (4), $q_i = \frac{a}{(n+1)b}\left(\frac{n}{n+1}\right)$, and $p = a - nbq_i = \frac{(2n+1)a}{(n+1)^2}$. The resulting firm profit is

$$\begin{aligned} \Pi_i^{col} &= \left(\frac{a}{n+1}\right)^2 \frac{1}{b} \left(\frac{n(2n+1)}{(n+1)^2}\right) \\ &= \Pi_i^{eq} \left(\frac{n(2n+1)}{(n+1)^2}\right) \end{aligned} \tag{12}$$

we need to show that these profits are larger than the equilibrium profits, or $\Pi_i^{col} > \Pi_i^{eq}$:

$$\begin{aligned}
\left(\frac{n(2n+1)}{(n+1)^2}\right)\Pi_i^{eq} &> \Pi_i^{eq} \\
n(2n+1) &> (n+1)^2 \\
n^2 - n - 1 &> 0
\end{aligned}$$

Since the left side of the last equation is increasing in $n > \frac{1}{2}$, we need only confirm the equation for $n = 2$ $(1 > 0)$. □

Proof of Remark 2.1: By equation (12) above,

$$\frac{\Pi_i^{col}}{\Pi_i^{eq}} = \frac{n(2n+1)}{(n+1)^2}$$

Which converges to 2, by repeated application of L'Hôpital's rule. □

Proof of Remark 2.2: Monopoly quantity in a Cournot model with linear demand is given by $Q^{mon} = \frac{a}{2nb}$. For decentralization-colluding firms, $q_i = \frac{na}{(n+1)^2 b}$. Thus, decentralization collusion is less efficient if

$$\begin{aligned}
& \frac{na}{(n+1)^2 b} < \frac{a}{2nb} \\
\equiv \quad & 2n^2 < (n+1)^2 \\
\equiv \quad & n^2 - 2n - 1 < 0 \\
\equiv \quad & n < 1 + \sqrt{2}
\end{aligned}$$

□

Proof of Proposition 3: First consider quantity collusion. Monopoly quantity is given by $\frac{a}{2b}$. Thus, a symmetric collusive scheme would assign output of $\frac{a}{2nb}$ to each participant, resulting in an industry price of $\frac{a}{2}$. Hence, $\Pi^{col} = \frac{a^2}{4nb}$, $\Pi^{eq} = \left(\frac{a}{n+1}\right)^2 \frac{1}{b}$. If one was to cheat, the optimal response derived from (3) would be to select the quantity

$$\begin{aligned}
q_i &= \tfrac{a}{2b} - \tfrac{1}{2} Q_{-i} \\
&= \tfrac{a}{2b} - \tfrac{1}{2}\left(\tfrac{(n-1)a}{2nb}\right) \\
&= \tfrac{a}{2nb}\left(\tfrac{n+1}{2}\right)
\end{aligned}$$

with resulting price and profit of $p = \frac{(n+1)a}{4n}$ and $\Pi^{ch} = \frac{a^2}{4nb}\left(\frac{(n+1)^2}{4n}\right)$. With Π^{col}, Π^{ch}, and Π^{eq} given by the above, we can obtain $\delta^{*(q)}$ by (8):

$$\begin{aligned}
\delta^{*(q)} &= \frac{\frac{a^2}{4nb}\left(\frac{(n+1)^2}{4n}\right)-\frac{a^2}{4nb}}{\frac{a^2}{4nb}\left(\frac{(n+1)^2}{4n}\right)-\left(\frac{a}{n+1}\right)^2\frac{1}{b}} \\
&= \frac{(n+1)^2-4n}{(n+1)^2-\left(\frac{4n}{n+1}\right)^2} \\
&= \frac{(n+1)^2}{(n+1)^2-4n}
\end{aligned}$$

For price competition, collusion profits are as above, $\Pi^{col} = \frac{a^2}{4nb}$, cheating entails undercutting the monopoly price by a tiny amount $\epsilon > 0$ resulting in capturing nearly the entire monopoly profit of $\Pi^{ch} = \frac{a^2}{4b}$, and the equilibrium of Bertrand competition in this context requires that each participant price at marginal cost, thus $\Pi^{eq} = 0$ and

$$\begin{aligned}
\delta^{*(p)} &= \left[\frac{a^2}{4b}-\frac{a^2}{4nb}\right] \Big/ \left[\frac{a^2}{4b}-0\right] \\
&= \frac{n-1}{n}
\end{aligned}$$

From the expressions above, we can confirm that $\lim\limits_{n\to\infty}\delta^{*(q)} = 1$ and $\lim\limits_{n\to\infty}\delta^{*(p)} = 1$. $\square$

Proof of Proposition 4: With Π^{eq} given by $\left(\frac{a}{n+1}\right)^2\frac{1}{b}$ and Π^{col} given by (12), we need to determine Π^{ch}, the profit from cheating. If a single firm, i, centralizes ($o_i = C$) while the remaining firms $j \neq i$ remain decentralized ($o_i = D$), then profits for the centralized firm are given by (11), letting $m = n-1$, which yields

$$\begin{aligned}
\Pi^{ch} &= \left(\frac{a^2}{(n+1)^2 b}\right)\left(\frac{2n+1}{n+2}\right)^2 \\
&= \Pi^{eq}\left(\frac{2n+1}{n+2}\right)^2
\end{aligned}$$

By (8):

$$\begin{aligned}
\delta^{*(o)} &= \frac{\Pi^{ch}-\Pi^{col}}{\Pi^{ch}-\Pi^{eq}} \\
&= \frac{\Pi^{eq}\left(\frac{2n+1}{n+2}\right)^2-\Pi^{eq}\left(\frac{n(2n+1)}{(n+1)^2}\right)}{\Pi^{eq}\left(\frac{2n+1}{n+2}\right)^2-\Pi^{eq}} \\
&= \frac{(2n+1)^2(n+1)^2-n(2n+1)(n+2)^2}{(2n+1)^2(n+1)^2-(n+2)^2(n+1)^2} \\
&= \frac{(2n+1)\left[n^2(n+1)+1\right]}{3(n+1)^3(n-1)}
\end{aligned}$$

First, we can confirm that the values of $\delta^{*(o)}$ for $n = 2, 3, 4$, are 65/81, 259/384, and 81/125, respectively, the last of which is less than 2/3. Next, brute force differentiation reveals that $\delta^{*(o)}$ is decreasing for $n < 3+\sqrt{10}$ and strictly increasing for $n > 3+\sqrt{10}$. Thus, we need only confirm that $\lim\limits_{n\to\infty}\delta^{*(o)} = \frac{2}{3}$, by repeated application of L'Hôpital's rule. $\square$

We will use the following Lemma in the proofs of Propositions 5 and 6.

Lemma 1. *In the presence of an external market, if exactly $m \in \{1,\ldots,n\}$ firms have adopted a decentralized form ($o_i = D$), the market price in the intermediate goods market* *is given by*

$$t = \frac{a}{(n-m+1)(m+1)} \tag{13}$$

Proof: From (4), the downstream division of a decentralized firm would produce:

$$q_i = \frac{a-(n-m+1)t}{(n+1)b} \tag{14}$$

Define the total output of the decentralized firms by

$$Q^{DEC} \equiv \sum_{i \mid o_i = D} q_i^d$$

Solving for t, the residual demand for upstream divisions is given by:

$$t = \frac{a - \frac{(n+1)}{m} b Q^{DEC}}{(n-m+1)} \tag{15}$$

An upstream division of a decentralized firm maximizes $\pi_i = tq_i = \frac{a - \frac{(n+1)}{m} bQ^{DEC}}{(n-m+1)} q_i$ yielding the first order condition:

$$q_i = \frac{ma}{2(n+1)b} - \frac{1}{2} Q_{-i}^{DEC}$$

The above implies that the total quantity traded in the external market is:

$$Q^{DEC} = \frac{m^2 a}{(n+1)(m+1)b}$$

Substituting into (15) yields the desired result. □

Proof of Proposition 5: When all firms are centralized, the external market is unused, so this is equivalent to the case without an external market. When all firms are decentralized, the transfer price is obtained from Lemma reflem by letting $m = n$:

$$t = \frac{a}{n+1}$$

which is equivalent to the transfer prices in the absence of an external market, leading to equivalent prices and profits. □

Proof of Proposition 6: To determine the profits from cheating, assume that Firm 1 is centralized while all other firms are decentralized. From (4), downstream divisions produce

$$q_1 = \frac{a+(n-1)t}{(n+1)b} \qquad\qquad q_i = \frac{a-2t}{(n+1)b}, i > 1$$

From Lemma 1, the transfer price is $t = \frac{a}{2n}$, implying

$$\begin{aligned}
q_1 &= \frac{a}{(n+1)b}\left(\frac{n-1}{n} + \frac{n+1}{2n}\right) \\
q_i &= \frac{a}{(n+1)b}\left(\frac{n-1}{n}\right), i > 1 \\
Q &= \frac{a}{(n+1)b}\left(n - 1 + \frac{n+1}{2n}\right) \\
p &= \frac{a}{(n+1)}\left(\frac{3n-1}{2n}\right)
\end{aligned}$$

While the equilibrium and collusive profits, Π^{eq} and Π^{col}, are the same as in the absence of an external market, the profit of a cheating firm (Firm 1) is given by:

$$\begin{aligned}
\Pi^{ch} &= pq_1 \\
&= \left(\frac{a^2}{(n+1)^2 b}\right)\left(\frac{3n-1}{2n}\right)^2 \\
&= \Pi^{eq}\left(\frac{3n-1}{2n}\right)^2
\end{aligned}$$

Again denoting by $\delta^{*(o)}$ the minimum discount rate that sustains collusion,

$$\begin{aligned}
\delta^{*(o)} &= \frac{\Pi^{ch} - \Pi^{col}}{\Pi^{ch} - \Pi^{eq}} \\
&= \frac{\Pi^{eq}\left(\frac{3n-1}{2n}\right)^2 - \Pi^{eq}\left(\frac{n(2n+1)}{(n+1)^2}\right)}{\Pi^{eq}\left(\frac{3n-1}{2n}\right)^2 - \Pi^{eq}} \\
&= \frac{(n+1)^2(3n-1)^2 - 4(n)^3(2n+1)}{(n+1)^2\left[(3n-1)^2 - 4(n)^2\right]} \\
&= \frac{n^4 + 8n^3 - 2n^2 - 4n + 1}{(n+1)^2(5n^2 - 6n + 1)}
\end{aligned}$$

Differentiation of $\delta^{*(o)}$ reveals that it is decreasing in n for $n > 1$. When $n = 2$, $\delta^{*(o)} \simeq .802 < 1$. □

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