

Stock-Related Compensation and Product-Market Competition*

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Abstract

The paper shows that as long as the stock market has perfect foresight, profits are distributed as dividends, and incentives are paid more than once or are deferred, stock-related compensation packages are strong incentives for managers to support tacit collusive agreements in repeated oligopolies. The stock market anticipates the losses from punishment phases and discounts them on stock prices, reducing managers' short-run gains from any deviation. When deferred, stock-related incentives may remove all managers' short-run gains from deviation making collusion supportable at any discount factor. The results hold with managerial contracts of any length.

JEL CLASSIFICATION: D43, G30, J33, L13, L21.

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1 Introduction

In a highly discussed empirical study, Michael Jensen and Kevin Murphy (1990) showed that until the end of the '80s, and contrary to the predictions of early agency theory, U.S. top-managers' compensation had on average a very low pay-performance sensitivity. Steven Kaplan (1994, 1998) found analogous results for other developed countries, such as Germany and Japan. These surprising findings led to concerns about the welfare implications of most common governance practices, since low-powered managerial incentives tend to soften product-market competition (e.g. Rajesh Aggarwal and Andrew Samwick, 1996; Giancarlo Spagnolo, 1996).

More recently, Brian Hall and Jeffrey Liebman (1998) have shown that the pay-performance sensitivity of U.S. top-managers' compensation has increased substantially in the last decade, mainly because of a widespread adoption of stock-related incentives, such as stock option plans. Stock-based managerial incentives are believed to be a powerful tool by which owners can motivate managers to work hard, to take risks, and to take into account the long-run effects of their choices (e.g. investments) on firms' profitability.¹ What about their effects on product markets? Does this trend towards stock-based incentives imply a more competitive attitude on the part of managers, so that concerns about tacit collusion and social welfare can be abandoned at least in the U.S.?

The results of this paper suggest that this may not be the case. Our model shows that as long as agents in financial markets have rational expectations and firms pay out part of their profits as dividends, most common stock-based managerial compensation plans greatly facilitate tacit collusion in long-run oligopolies. We find that stock-related compensation reduces managers' incentives to break any tacit agreement in any repeated oligopoly, and may make the joint monopoly agreement supportable at any level of the discount factor.

The phenomenon of tacit collusion in long-run oligopolies has been fruitfully studied in the last three decades within a discounted repeated games framework.² However, most classical supergame-theoretic analyses of collusion confined themselves to the standard assumption that firms maximize the discounted sum of expected per-period profits. In the real world many interacting factors affect firms' objective function, and consequently firms' ability to collude. Among these factors the most important are probably managerial incentives.³

¹See, for example, Sanjai Bhagat *et al.* (1985); Kevin Murphy (1985); Matthew Jackson and Edward Lazear (1991); Myron Scholes (1991); Bengt Holmström and Jean Tirole (1993).

²Classical references include James Friedman (1971); Robert Aumann and Lloyd Shapley (1976); Ariel Rubinstein (1979); Edward Green and Robert Porter (1984); Drew Fudenberg and Eric Maskin (1986); Julio Rotemberg and Garth Saloner (1986); Dilip Abreu (1986, 1988).

³This was recognized early by scholars interested in firm behavior. See Herbert Simon (1957);

A number of authors have already explored the strategic effects of delegating decision power to managers with preferences/incentives different from those of owners in oligopolies (e.g. John Vickers, 1985; Chaim Fershtman, 1985; Fershtman and Kenneth Judd, 1987; Steven Sklivas, 1987; Fershtman, Judd, and Ehud Kalai, 1991; Michael Katz, 1991; David Reitman, 1993). Most contributions to this literature focus on the strategic effects of managerial incentives in two-stages models, where owners simultaneously choose their managers' incentive schemes before a one-shot oligopolistic market interaction between manager-led firms. In Fershtman and Judd (1987) and Sklivas (1987) (FJS from now on), firm owners can precommit to a more aggressive market behavior by choosing the parameters of a managerial contract that is linear in profits and sales revenue. In the case of quantity competition, the simultaneous attempts to gain a strategic advantage by precommitting through managerial incentives offset one another and lead to higher output and lower profits than in the standard Cournot-Nash equilibrium.

In probably the closest paper in spirit to the present one, Reitman (1993) has shown that if one lets owners introduce stock options in a FJS-type model, these may curb managers' overly aggressive behavior and bring back the original Cournot-Nash equilibrium. This result is due to the non-linearity of stock options in stock price, which induces a discontinuity in managers' best response function and generates other equilibria than the FJS one. The Pareto-dominant among the symmetric equilibria corresponds to the no-delegation Cournot-Nash equilibrium, so that if managers coordinate on this equilibrium the "delegation Prisoner's Dilemma" identified by FJS disappears and, eventually, the ability to precommit through managerial incentives does not affect the outcome of the Cournot game.

We depart from most previous work on delegation by following Spagnolo (1996) in allowing for repeated interaction, so that tacit collusion can be analyzed with the tools of repeated games.

We focus on stock-based compensation plans as usually designed in the real world according to Stacey Kole's (1997) empirical findings. These plans are typically quite liquid (when not in cash, they have few restrictions on resale or transfers of shares) and pay managers stock-based bonuses for several consecutive years.

The pro-collusive effect that we identify is linked to the fact – forcefully stressed by Bengt Holmström and Jean Tirole (1993) – that the stock price incorporates additional information with respect to a firm's profits, information strictly related to the firm's future profitability. Incentive schemes based on stock price link managers' *present* compensation to the stock market's expectations about firms' *future* profitability. When a breach of a tacit collusive agreement occurs, a stock market

William Baumol (1958); Richard Cyert and James March (1963); Robin Marris (1964); Oliver Williamson (1964); Michael Jensen and William Meckling (1976).

with rational expectations anticipates the negative effect of the breach on firms' future profitability linked to the forthcoming price/quantity war, and immediately discounts it on stock prices (for a real world example see e.g. Jonathan Laing, 1997). Because this effect occurs in the very same period in which a manager deviates from a collusive agreement, incentives linked to stock price directly reduce managers' short-run gains from deviation.

Furthermore, we find that when stock-based incentives are deferred, as they often are in reality, the first pro-collusive effect is reinforced by the fact that the already limited beneficial effect on the stock price of short-run profits from a unilateral deviation may be completely gone at the time when the manager receives the bonus. Then, the manager is left with no incentive whatsoever to deviate, which further stabilizes collusive agreements.

Interestingly, we also find that these pro-collusive effects are not reduced, and may well be reinforced when managerial contracts are short-term.

Although this paper is close in spirit to Reitman (1993), the effects identified here are very different from the effect discussed there. Both the "expectations effect" and the "deferred incentives effect" are not linked to the non-linearity of stock options; they apply to any form of managerial compensation that is positively related to stock price. Also, the effects of managerial incentives discussed here have a strong impact on the equilibrium outcome of the oligopoly game. In our model deferred stock-related managerial incentives make the joint monopoly outcome supportable even when owners or profit-maximizing managers could not support any collusive agreement. Moreover, the results in this paper are not specific to Cournot competition; they extend to any other kind of repeated oligopoly.

We follow the literature on strategic delegation by assuming observable and binding managerial incentives. This assumption has been criticized on the ground of its robustness with respect to secret renegotiation (Mathias Dewatripont, 1988; Katz, 1991). However, as Reitman (1993) also made clear, for the case that we are focusing on this assumption is close to reality. The adoption of stock-based managerial incentive plans, such as stock options, normally requires shareholders' approval. Shareholders' approval must be obtained in open shareholders' meetings, and these make stock-based incentives and their renegotiation almost public information.⁴

Finally, the results of this paper are related to, but quite distinct from those in Fershtman, Judd, and Kalai (1991), Michele Polo and Piero Tedeschi (1992), and Aggarwal and Samwick (1996). Fershtman, Judd, and Kalai (1991) obtain

⁴Consider, for example, the recent world-wide discussions on the stock-option plan in Walt Disney's management's new compensation package. The results of this paper would be of interest even if secret renegotiation were possible, as the *costs* typically linked to contract renegotiation would still give commitment value to managerial incentives (see the discussion in Section 6.7).

a full “folk theorem” for two-stage observable delegation games by using “target compensation functions” that award agents a fixed prize as long as managers keep the principal’s utility above a certain level. Polo and Tedeschi (1992) and Aggarwal and Samwick (1996) obtain cooperative outcomes in two-stage delegation games by allowing managerial contracts to be related to competing firms’ profits. Here we work with repeated oligopoly models, instead, and we obtain full collusion at any discount factor with the empirically observed stock-related managerial incentive plans, which are not target compensation functions and which are conditional only on the firm’s own stock price.

The rest of the paper is organized as follows: Section 2 presents the model; Section 3 discusses the pro-collusive effect linked to stock-market expectations; Section 4 considers deferred stock-based incentives; Section 5 endogenizes owners’ choice of managers’ contracts and discusses the effect of their length; Section 6 extends and discusses the results; and Section 7 briefly concludes. All proofs are in the appendix.

2 The model

2.1 Product market

There are N symmetric firms, indexed by the subscript i . Market structure is a standard Cournot oligopoly (stage game) infinitely repeated in discrete time under complete and perfect information.

Let $\pi_i(q_i, q_{-i}) = P(q_i + q_{-i})q_i - c(q_i)$ denote firm i ’s static (stage-game’s) profit function, where q_i represents firm i ’s output, q_{-i} the quantity produced by the other $N-1$ firms, $P(\cdot)$ the inverse demand function and $c(\cdot)$ firms’ cost function.

We assume that the inverse demand function satisfies $P' < 0$ and $P'' \geq 0$, that profits are concave in firms’ own output, and that marginal profits are decreasing in rivals’ output, so that static reaction functions are continuous and downward sloping.

Let $\pi_i^N = \pi_i(q_i^N, q_{-i}^N)$ denote firm i ’s static (stage-game’s) profits when firms produce the Cournot-Nash equilibrium output vector $q^N = (q_1^N, \dots, q_n^N)$, $\pi_i^A = \pi_i(q_i^A, q_{-i}^A)$ denote owner i ’s static payoff from a stationary tacit agreement A to restrict production to the vector $q^A = (q_1^A, \dots, q_n^A)$, and $\hat{\pi}_i^A = \pi_i(\hat{q}_i(q_{-i}^A), q_{-i}^A)$ denote his static payoffs from unilaterally deviating from A by producing the static best response output $\hat{q}_i(q_{-i}^A)$. Analogously, $\pi_i^M = \pi_i(q_i^M, q_{-i}^M)$ will denote firm i ’s profits at the joint monopoly market outcome q^M , and $\hat{\pi}_i^M = \pi_i(\hat{q}_i(q_{-i}^M), q_{-i}^M)$ will denote static payoffs from unilaterally deviating from the joint monopoly collusive agreement.

Time is indexed by the superscript $t = 1, 2, 3, \dots$ (the time superscript is absent when we refer to a representative period) and δ denotes the intertemporal discount

factor common to all agents, owners and managers. We assume that at each point in time t each agent maximizes the discounted sum of expected monetary gains. So each owner i maximizes the discounted sum of firm i 's expected profits $U_i^t = \sum_{\tau=1}^{\infty} \delta^\tau \pi_i^{t+\tau}$.

To simplify exposition we focus on stationary collusive agreements enforced by “unrelenting” trigger strategies, that is, by the threat of reverting to the non-cooperative Cournot-Nash equilibrium forever (Friedman, 1971).⁵ Also, to make things more interesting, we assume throughout that the discount factor is too low for owners, or for managers with incentives in line with owners’ objectives (“profit-maximizing managers” from now on), to support the joint monopoly collusive agreement in subgame-perfect equilibrium.

2.2 Financial market

We assume the following:

1. The stock market is perfectly informed, rational, and skilled in game theory: it fully understands equilibria selected in the product market.
2. The value of a firm (of its shares) in one period depends positively upon the discounted profit stream it is expected to generate and on the realized profits which have not yet been distributed as dividends (we assume no physical assets to simplify exposition).
3. At the end of each period realized profits are paid out to shareholders as dividends (but see Section 5.1).

Under these assumptions the price of one share of firm i , P_i^t , at the end of period t before period t 's dividends are paid out is

$$P_i^t = \frac{1}{\varphi_i} \left[\pi_i^t + \sum_{\tau=1}^{\infty} \delta^\tau \pi_i^{t+\tau} \right],$$

where φ_i is the (large) number of firm i 's shares.

2.3 Managerial contracts

According to Kole (1997), most common stock-based managerial incentive plans are relatively liquid, such as stock options with stock appreciation rights (SARs) or

⁵In Section 6.5 and Appendix 2 we show that the choice of more sophisticated strategies (e.g. finite length, “optimal,” or renegotiation-proof punishment strategies) does not affect our conclusions. Also, at the cost of a more cumbersome exposition the results can easily be extended to encompass non-stationary collusive agreements.

share-performance cash bonuses. In most cases the effect of these incentive plans is deferred and distributed in time, probably to reduce the much advertised risk of costly managerial “short-termism” in investment choices.⁶ For example, for stock options the typical vesting schedule includes a “wait to exercise” of 12 months for the first quarter of the award, after which the remainder of the award becomes available in equal installments over the next three years. We will focus mainly on the product-market effects of these more common stock-related incentive plans.⁷

We assume the following:

1. Firms are run by managers with observable incentive contracts which may be linked to stock price (as in the case of stock options or cash bonuses positively related to stock price).⁸
2. When managers receive compensation in stock or stock options, they are not required to keep the firms’ shares; the instant in which they receive their compensation they sell their shares or options in order to diversify their portfolio.
3. When a manager is indifferent about available actions because they all lead to the same wage, the manager chooses the action that maximizes the owner’s objective function.

⁶See, e.g. MC Narayanan (1985); Jeremy Stein (1989); Lucian Bebchuck and Lars Stole (1993); and John Bizjak *et al.* (1993).

⁷Restricted stock awards and stock option plans with restrictions on resale/transfer of the shares are used by a minority of firms. We discuss the product-market effects of these other incentives in Section 6.2 (managerial ownership).

⁸Here we follow the literature by neglecting the possibility that an owner does not hire a manager (e.g. Fershtman and Judd, 1987; Sklivas, 1987; Reitman; 1993). In previous work one seldom sees explicit justifications for this choice, perhaps because they are considered obvious. The doubts of a referee persuaded us that it is worthwhile to provide some justification here.

On the empirical side, “...in almost all significant industries, the managers making pricing and output decisions do not own the firm that they direct...” (Katz, 1991, p. 307). The theoretical justification, which is probably also the reason behind the empirical regularity, is that owners’ opportunity cost of running their firm personally can be safely assumed far larger than that of a professional manager. The focus here is on large oligopolistic firms in mature industries, where ordinary management is a routine job that entails no special pleasure or excitement (as it might entail for Bill Gates in the rapidly growing field of the information industry). If ownership is diffuse, the enormous costs of collective action will force shareholders to delegate firm management, and even to delegate the manager’s supervision to directors. If ownership is concentrated, the owners’ huge wealth will make them value the time required to administrate the firm much more than any less wealthy professional manager. Since managers’ compensation can be kept strictly smaller than the owners’ opportunity cost of running their firms in all states, delegation will always occur. Therefore the relevant issue is not whether to hire a manager, but how to pay him.

2.4 Useful benchmarks

Given the common discount factor, any collusive agreement A is sustainable in subgame-perfect equilibrium by profit-maximizing managers as long as discounted expected profits from sticking to the agreement exceed expected profits from deviating, that is,

$$\frac{\pi_i^A}{1-\delta} \geq \widehat{\pi}_i^A + \frac{\delta\pi_i^N}{1-\delta}. \quad (1)$$

Let \overline{A} denote the “most collusive” symmetric agreement that profit-maximizing managers can support at the given discount factor, the one which makes (1) hold as an equality, where $\pi_i^{\overline{A}} < \pi_i^M$. Alternatively, one can rewrite (1) in terms of the minimum level of the discount factor $\underline{\delta}^A$ at which profit-maximizing managers can support a given agreement A , that is,

$$\delta \geq \underline{\delta}^A = \frac{\widehat{\pi}_i^A - \pi_i^A}{\widehat{\pi}_i^A - \pi_i^N}.$$

It is useful to state a simple lemma:

Lemma 1 *The Cournot-Nash equilibrium outcome (the equilibrium outcome of the stage game played by profit-maximizing managers) is also a Nash equilibrium outcome of the stage game played by managers under incentive contracts positively related to stock price.*

The statement follows directly from the assumptions. In the static interaction, if all other managers choose the Cournot-Nash production level then a manager paid as a function of stock price cannot gain by choosing a different production level: any other choice will reduce the firm’s profits, the stock price, and therefore the manager’s compensation. This lemma makes sure that the reversion to the static Cournot-Nash equilibrium remains a credible punishment strategy when managers under stock-based compensation are running the firms, and allows us to study the effects of these incentives on firms’ ability to collude by plugging managers’ compensation function into condition (1).

3 Stock-related compensation, expectations, and collusion

In this and in the next section we analyze the product-market effects of stock-related managerial compensation packages by taking them as given, as observed in reality.

In the following section we endogenize managerial contracts by leaving owners free to choose managerial incentives other than stock-related ones.⁹

3.1 “Small” compensation packages

We first follow the literature (e.g. Fershtman and Judd, 1987; Sklivas, 1987; Reitman, 1993) by neglecting the direct effect of managers’ compensation on firms’ profits and stock prices. In our model, as in most previous models of strategic delegation, managers’ task is only to set the level of a strategic variable. Absent issues of managerial effort and moral hazard there is no reason for owners to give managers large amounts of incentive pay, since as long as the manager is paid in the right way at the margin a small incentive component with negligible effects on profits and stock prices is sufficient to induce the desired behavior.¹⁰

Consider the following class of stock-related managerial incentive contracts.

Definition 1 *Incentive contract class A (ICA):* *In each period t the manager of firm i receives a compensation positively related to the stock price $f_i(P_i^t)$ – where f_i is any monotone and strictly increasing function – before period t profits are paid out as dividends.*

Disregarding the negligible effects of small managerial bonuses on firms’ stock prices, and given that under ICA-type contracts managers are paid before the distribution of dividends, the value of a firm’s share at the time when they receive their compensation is exactly as in the example in Section 2.2. Then, the incentive compatibility condition for a stationary collusive agreement A to be supportable by

⁹The results of these two sections are the crucial ones, since they unveil an important side effect of empirically observed governance practices. In fact, although for completeness we show (in Section 5) that stock-related managerial incentives are the outcome of a collusive equilibrium where owners are free to choose other types of managerial compensation, we could not seriously argue that the only or the main reason why stock-related managerial incentives are popular is their pro-collusive effect. We believe that few practitioners, if any, are aware of the pro-collusive effects identified here. Stock-related incentives are usually adopted for their many positive effects on managerial behavior already highlighted in the literature. Independent of the reason why stock-related incentives are adopted, this and the next section show that beside their known beneficial effects, a less known and socially harmful side effect probably contributes to the improvements in firm profitability these incentives appear to generate.

¹⁰In what follow we will focus only on the incentive part of managers’ compensation $f(P)$. However, managers’ actual compensation will be some function $A + Bf(P)$, where the parameters A and B can be freely set to reflect conditions on managers’ labor market. Whatever A and B are, therefore however small B is, managerial behavior will still be driven by only the marginal incentive component $f(P)$ (see Fershtman and Judd, 1987, footnote 3).

the manager of firm i under a compensation package in the ICA class is

$$\frac{1}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) \right] + \frac{\delta}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \right], \quad (2)$$

where the inequality is strict because of assumption 3 in Section 2.3.

We can now state the first result.

Proposition 1 *Suppose firms are led by managers under incentive contracts in the class ICA and managerial compensation has a negligible effect on stock price. Then:*

(i) *The minimum discount factor at which any collusive agreement can be supported in subgame-perfect equilibrium is strictly lower than when firms are led by profit-maximizing managers;*

(ii) *For a given discount factor, more profitable collusive agreements become supportable than when firms are led by profit-maximizing managers.*

The intuition behind this result is the following. The short-run incentive to deviate from any collusive agreement is lower for a manager under an ICA-type contract than for a profit-maximizing one because the value of the shares of a firm that deviates from a collusive agreement does not increase as much as short-run profits in the period in which the deviation occurs. This is because, as noted by Holmström and Tirole (1993), the stock price contains more information than accounting profits, and in the case of a deviation the additional information is about the forthcoming punishment phase, that is, bad news. The stock market forecasts that the deviation will be followed by a production war leading to a period of low profits and adjusts firms' stock prices accordingly. Therefore a negative effect of the punishment phase occurs on (deviating and non-deviating) managers' compensation already in the *same* period in which the deviation occurs. In addition, expected stock price and related bonuses in the periods that follow the deviation are low because gains from deviation are distributed and per-period profits are depressed by the punishment phase. These effects make managers under stock-related compensation more prone to collude than profit-maximizing ones.

3.2 “Large” compensation packages

We wrote before that we believe stock-related managerial incentives are adopted in reality not because they may be pro-collusive, but because of their positive effects on managerial behavior already highlighted in the literature (see Introduction). To realize these other effects, however, the amount of stock-related pay may matter a lot. Indeed, in some real world cases managerial compensation packages appear “heavy” enough to noticeably influence the firms' stock price. To take these cases

into account we turn now to stock-related incentives which, for unmodelled reasons, must be large enough to have non-negligible direct effects on the firm's stock price.

In this case, when the manager is hired under a contract in the class ICA, the price of one share of firm i , P_i^t , at the end of period t before period t 's dividends are paid out is

$$P_i^t = \frac{1}{\varphi_i} \left[\pi_i^t - f(P_i^t) + \sum_{\tau=1}^{\infty} \delta^\tau \left(\pi_i^{t+\tau} - f(P_i^{t+\tau}) \right) \right]. \quad (3)$$

To compare the condition for a manager under stock-related compensation to be willing to sustain collusion with the benchmark condition (1) we need to calculate the stock price, and because of the recursive structure of (3) we need to be more precise about the function f . The more natural thing to do, in line with most previous work on delegation, is to let f be a linear function.

Definition 2 Incentive contract class A^L (ICA^L): In each period t the manager of firm i receives $\alpha_i P_i^t$, where $0 < \alpha_i < \varphi_i$, before period t profits are paid out as dividends.

The incentive compatibility condition for a stationary collusive agreement A to be supportable by the manager of firm i under a compensation package of the ICA^L type is

$$\frac{1}{1-\delta} \alpha_i P_i^A > \alpha_i \hat{P}_i^A + \frac{\delta}{1-\delta} \alpha_i P_i^N, \quad (4)$$

where:

$$P_i^A = \frac{1}{\varphi_i} \left(\frac{\pi_i^A - \frac{\alpha_i}{\varphi_i} P_i^A}{1-\delta} \right) \Rightarrow P_i^A \frac{\varphi_i(1-\delta) + \frac{\alpha_i}{\varphi_i}}{\varphi_i(1-\delta)} = \frac{1}{\varphi_i} \frac{\pi_i^A}{1-\delta} \Rightarrow P_i^A = \frac{1}{\varphi_i} \frac{K \pi_i^A}{1-\delta},$$

with $K = \frac{\varphi_i(1-\delta)}{\varphi_i(1-\delta) + \frac{\alpha_i}{\varphi_i}} < 1$;

$$P_i^N = \frac{1}{\varphi_i} \left(\frac{\pi_i^N - \frac{\alpha_i}{\varphi_i} P_i^N}{1-\delta} \right) \Rightarrow P_i^N = \frac{1}{\varphi_i} \frac{K \pi_i^N}{1-\delta};$$

and

$$\begin{aligned} \hat{P}_i^A &= \frac{1}{\varphi_i} \left(\hat{\pi}_i^A - \frac{\alpha_i}{\varphi_i} \hat{P}_i^A + \delta \frac{\pi_i^N - \frac{\alpha_i}{\varphi_i} P_i^N}{1-\delta} \right) \Rightarrow \hat{P}_i^A \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right) = \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \delta \frac{K \pi_i^N}{1-\delta} \right), \\ &\Rightarrow \hat{P}_i^A = \frac{\hat{\pi}_i^A + \delta \frac{K \pi_i^N}{1-\delta}}{\varphi_i \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)}. \end{aligned}$$

We can now state the following result.

Proposition 2 *Suppose firms are led by managers under incentive contracts in the class ICA^L . Then:*

(i) *The minimum discount factor at which any collusive agreement can be supported in subgame-perfect equilibrium is strictly lower than when firms are led by profit-maximizing managers;*

(ii) *For a given discount factor, more profitable collusive agreements become supportable than when firms are led by profit-maximizing managers.*

Although the proof is algebraically more cumbersome, the intuition behind the result is exactly as for Proposition 1. The case of linear stock-related incentives with non-negligible effects on the stock price does not differ in any substantive way from that of stock-related incentives with negligible effects on the stock price.

For the sake of crispness, in the remainder of the paper we will follow the literature in focusing on “small” compensation packages. Correspondent results for the case of “large” compensation packages can be obtained as done in this section (and in the proof of Proposition 2 in Appendix 1).

3.3 Stock options

To make the results more concrete, consider the case of the most popular stock-based managerial incentives: stock option plans. Stock options are not strictly increasing functions of the stock-price (for all strike prices above the stock price the value of the option is constant and equal to zero), therefore we could not simply apply the results in the previous subsections to this case.

Definition 3 *Incentive contract class A^P (ICA^P):* *In each period t the manager receives the right to buy a number γ_i of shares at a predetermined price \underline{P}_i , both of which are constant across time periods, before period t profits are paid out as dividends.*

Again, because under these contracts managers get paid before the distribution of dividends, the value of a share at the time when they can cash their stock options includes that period’s profits. Then the incentive compatibility condition for a stationary collusive agreement A to be supportable by the manager of firm i under a compensation package of the ICA^P type is

$$\frac{1}{1-\delta} \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \frac{\pi_i^A}{1-\delta} - \underline{P}_i \right], 0 \right\} > \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) - \underline{P}_i \right], 0 \right\} + \frac{\delta}{1-\delta} \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \frac{\pi_i^N}{1-\delta} - \underline{P}_i \right], 0 \right\}. \quad (5)$$

In each period the stock options are “in the money” (valuable) if the price of the shares P_i^t at the end of the period is higher than \underline{P}_i . We can state the following result.

Proposition 3 *Suppose firms are led by managers under incentive contracts in the class ICA^P , with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \forall i$. Then:*

(i) *The minimum discount factor at which any collusive agreement delivering per-period profits π_i^A can be supported in subgame-perfect equilibrium is strictly lower than when firms are led by profit-maximizing managers;*

(ii) *For a given discount factor, more profitable collusive agreements become supportable than when firms are led by profit-maximizing managers.*

Again, the intuition is that the short-run incentive to deviate from any collusive agreement is lower for a manager under an ICA^P -type contract because the stock market forecasts the production war that follows a deviation and adjusts firms’ stock price accordingly, anticipating the negative effects of the punishment during the same period in which the deviation occurs. One can also state the following corollary.

Corollary 1 *Suppose the repeated oligopoly game is played by managers under incentive contracts in the class ICA^P . Then, the minimum discount factor at which any collusive agreement can be supported in subgame-perfect equilibrium is independent of γ_i and is minimized when $\underline{P}_i \leq \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \forall i$.*

(As for previous results, a corresponding statement holds for the most profitable agreement supportable at a given discount factor.) The corollary implies that the pro-collusive effect is stronger when the strike price is so generous that stock options are valuable whatever collusive equilibrium is chosen.

4 Deferred stock-related compensation

4.1 The general case

Consider a slightly different class of contracts by which in each period managers receive their stock-related bonuses only after having distributed that period’s profits as dividends.

Definition 4 Incentive contract class B (ICB): *In each period t the manager receives a compensation positively related to stock price $f_i(P_i^t)$ – where f_i is any monotone and strictly increasing function – after period t profits are paid out as dividends.*

Because managers get paid after the distribution of dividends, the value of the shares when they cash their options does not incorporate present profits π_i^t . Therefore when managers under ICB-type contracts cash their bonuses the stock price is

$$P_i^t = \frac{1}{\varphi_i} \left[\sum_{\tau=1}^{\infty} \delta^\tau \pi_i^{t+\tau} \right].$$

Also, consider stock-related incentive plans such that managers can cash the bonuses only some time after having left the firm. This form of compensation is often introduced to avoid managers (who may be planning to leave the firm) taking actions against the long-run interest of shareholders in order to improve their short-run market valuation, and to maintain an incentive for managers close to retirement to work hard. To keep things simple we assume that managers face a constant per-period probability $(1 - \eta)$ of leaving the firm (because of a take-over, say, or because they find a better job).

Definition 5 *Incentive contract class C (ICC):* *In each period the manager receives a wage, which we normalize to zero, and in the period after he stops working for the firm, say τ periods after he started, he receives additional compensation positively related to stock price $(1+r)_i^\tau f_i(P_i^\tau)$ – where f_i is any monotone increasing function and $\frac{1}{1+r} = \delta$.*

Then one can state the following result.

Proposition 4 *Suppose firms are led by managers under incentive contracts in the class ICB or ICC. Then, the joint monopoly collusive agreement can be supported in subgame-perfect equilibrium at any level of the discount factor.*

The intuition behind the proposition is somewhat analogous to that behind Propositions 1 to 3, but here the mechanism is more extreme. For a manager under a contract in the class ICB or ICC there is no incentive whatsoever to deviate from collusion. After short-run profits from a deviation are paid out as dividends, the price of the shares of the deviating firm (and therefore its manager’s compensation) depends *only* on stock market expectations about the firm’s future profitability, and therefore it falls. Managers under contracts in the classes ICB and ICC incur a net loss when they deviate from a collusive agreement without ever being able to capture any of the short-run gains from deviating.¹¹

¹¹Note that nothing changes if managers under ICC-type contracts know exactly when they will stop working for their firms. What is important is that after managers have left, firms go on producing so that stock market expectations about firms’ future profitability can influence the leaving managers’ compensation through stock prices.

4.2 Stock options

Consider now stock option plans with deferred realization.

Definition 6 *Incentive contract class B^P (ICB^P):* *In each period t the manager receives the right to buy a number γ_i of shares at a predetermined price \underline{P}_i , both of which are constant across time periods, after period t profits are paid out as dividends.*

Because managers get paid after the distribution of dividends, the value of the shares when they cash their stock options does not incorporate present profits π_i^t . Also, consider stock option plans such that managers can exercise the options only some time after retirement. Again, we assume that in every period the manager faces a constant probability $(1 - \eta)$ of leaving the firm.

Definition 7 *Incentive contract class C^P (ICC^P):* *In each period the manager receives a flat wage, which we normalized to zero, and in the period after he stops working for the firm, say τ periods after he started, the manager receives a number of stock options $\gamma_i(1 + r)^\tau$ - where $\frac{1}{1+r} = \delta$ - with a strike price \underline{P}_i and γ_i and \underline{P}_i constant across time periods.*

Then one can state what follows.

Proposition 5 *Suppose the repeated oligopoly game is played by managers under incentive contracts in the class ICB^P or ICC^P , with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^M}{1-\delta} \right) \forall i$. Then, the joint monopoly collusive agreement can be supported in subgame-perfect equilibrium at any level of the discount factor.*

The intuition behind this result is fully analogous to that behind Proposition 4.

5 On the choice and length of managerial contracts

In the previous sections managers were assumed to have an infinite horizon, as the firm, and to be under stock-related compensation. Although managers do tend to stay with one firm for long periods, in reality explicit managerial contracts are rarely life-long. Furthermore, in reality owners are free to change managerial incentives in time. In this section we show that the results in the previous sections apply when explicit managerial contracts are short-term and shareholders can change managerial incentives in time. To do this, we assume that managerial contracts last a finite

number of periods T , and that owners can choose between profit-related or stock-related incentives. Every T periods owners must decide whether to reconfirm the current manager and his incentive contract or to replace one or both of them. This situation can be modelled as a repeated game whose stage game is composed of several consecutive steps. To simplify exposition we assume that all managers' explicit contracts last the same number of periods T and are signed (and expire) simultaneously. It will become clear below that the results of this section are not dependent on these simplifying assumptions. To further simplify we focus on symmetric stationary collusive agreements and assume that none of them are supportable when profit-maximizing managers are in control.

The stage game of the oligopoly supergame will now be composed of $T + 1$ steps. The timing of a stage game beginning in period t will be as follows.

Stage game t

- Step 1: Owners hire managers and choose their incentive contracts.
- Steps 2 to $T + 1$: All players observe the outcome of the previous step, then managers choose output levels.

In other words, in each stage game in Step 1 each of the owners simultaneously chooses a manager and his incentive contract for the T following periods. From Step 2 on, the managers choose simultaneously output in T consecutive static Cournot market interactions. This means that a new stage game will only begin every $T + 1$ periods.

We can now state the following result.

Proposition 6 *Any collusive agreement supportable by managers under life-long stock-related incentive contracts can be supported as a subgame-perfect equilibrium outcome of the infinitely repeated delegation game which has the multistage game above as its stage game.*

That is, the pro-collusive effects identified in Sections 3 and 4 apply when owners are free to choose profit-related incentives instead of stock-related ones and when explicit managerial contracts are short-term. This is because, even though explicit managerial contracts last a finite number of periods, owners are free to agree with their managers on *implicit* employment contracts, which are long-term by definition (e.g. Bentley MacLeod and James Malcomson, 1989; Lorne Carmichael, 1989). In this framework, an owner's choice of a different explicit managerial contract than the agreed stock-related one that leads managers to sustain collusion is considered a deviation and punished with the interruption of cooperation.

On the side of managers, the negative effects of stock-based incentives on short-run gains from deviations highlighted in Sections 3 and 4 remain when explicit managerial contracts are short-term. Regarding owners, they have no incentive whatsoever to deviate by renegeing on the implicit contract to reconfirm the manager and the explicit stock-related incentives that lead him to sustain collusion, since changes of management or incentives are observable and other firms' managers can react before any short-run gain from deviation can be realized. This is also why the proposition can easily be proved to hold when explicit managerial contracts are not signed (do not expire) simultaneously or have different durations.

Note that the converse of the proposition is not true. In fact, the incentive compatibility conditions for the self-enforcing implicit contracts with short-term explicit contracts that replicate the results in the previous sections can be less stringent than the incentive compatibility conditions with long-term explicit contracts.

Corollary 2 *If managers have stock-related incentives in the class ICA or in the class $ICAP$ with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \forall i$, then the shorter is the length T of the explicit managerial contracts, the smaller is the minimum discount factor at which any collusive agreement can be supported (and, for a given discount factor, more profitable agreements become sustainable) in subgame-perfect equilibrium in the delegation supergame.*

Again, owners have no incentives to renege on the implicit managerial contracts, while the negative effect of stock-based incentives on managers' short-run gains from deviations highlighted in Sections 3 does not depend on the length of explicit managerial contracts. Additionally, with short-term contracts at the end of the stage in which a deviation occurs the deviating manager is fired and kept at his reservation wage forever after. Implicit labor contracts are enforced by leaving to the agent (the manager) a stake of the expected (collusive) surplus from the employment relation (MacLeod and Malcomson, 1989). Therefore the threat of termination, with the loss of future rents it implies, has an additional pro-collusive effect on the manager that adds to that identified in Section 3. Because termination is closer in time the shorter is the length of explicit managerial contracts, the smaller is T the stronger is the overall pro-collusive effect.

6 Extensions and discussion

6.1 Alternative specifications of the model

6.1.1 *Dividend policy*

The pro-collusive effects identified in Sections 3 and 4 are driven by stock-based managerial incentives being paid for several consecutive periods (ICA, ICB) or being deferred (ICB, ICC), and by assumption 3 in Section 2.2 by which all realized profits are paid out as dividends (so that the stock price at time t depends mostly on market expectations about firms' profitability *after* t). While the time structure of stock-related incentives in our model reflects the evidence on most common real-world arrangements (Kole, 1997), the assumption that all profits are distributed as dividends is extreme; it has been made to simplify exposition and make results more clear-cut. In fact, this last assumption is not necessary for the pro-collusive effects we identified. It is easy to check that analogous results hold as long as any positive fraction of firm profits is paid out as dividends. In a perfect information world, profits distributed in past periods (and distributed short-run gains from deviation) do not enter a firm's present value, therefore future profits have a relatively larger weight than past profits in the determination of a firm's stock price. This is enough for stock-related incentives to be pro-collusive: by substituting in conditions (2), (4), (5), and in the proofs of Propositions 4 and 5, one can see that the only case in which the behavior of managers under stock-based incentives corresponds to that of profit-maximizing managers or owners, so that the pro-collusive effects disappear, is when firms *never* pay out any fraction of the short-run gains from a deviation as dividends.

Of course, the smaller the fraction of profits paid out as dividends, the closer are managers' and owners' objectives, and the weaker are the pro-collusive effects of stock-related compensation.

6.1.2 *Market structure*

The results above are robust to changes in modelling assumptions about market structure. It is straightforward to check that they apply to repeated oligopolies other than the Cournot type. All results and proofs are stated using only profit streams π_i^N , π_i^M , $\hat{\pi}_i^M$, etc., with no direct reference to the specific strategic variables used in the product market. We can reinterpret the profit stream as deriving from any other repeated oligopoly (for example, setting $\pi_i^N = 0$ in the case of homogeneous good Bertrand competition), and note that all proofs continue to hold.

6.2 Profit sharing and managerial ownership

We have focused on liquid incentives related to stock price. What if owners choose managerial contracts that also incorporate a profit-sharing component, or if managers are required to retain firm's shares received as a bonus?

It is straightforward to check that any additional profit-sharing component leads managers to behave more like owners; it dilutes the pro-collusive effect of stock-based incentives without bringing any countervailing benefit. Because of this, it is easy to show that in our model the choice to have a profit-sharing incentive component besides stock-related incentives is always dominated (see the section "Profit Sharing" in Appendix 1).

Analogous reasoning applies when managers are required, or simply choose to keep in their portfolios the shares they get each period as bonuses. If managers under contracts in the classes ICA or ICB keep the shares they receive each period, they will in time own an increasing fraction of the firm. This leads them to receive a larger and larger share of the profits realized in each period as dividends, with an effect on product-market behavior identical to that of a profit-sharing incentive component increasing in time. The more shares the manager owns, the more dividends he receives, the more he behaves like an owner, the smaller is the set of collusive agreements he is willing to support, and the higher is the minimum discount rate at which he is willing to stick to any given collusive agreement. Summarizing:

Remark 1 *Profit-sharing incentives, restrictions on the resale or transfer of firm shares received as bonuses, and, more generally, managerial ownership dilute the pro-collusive effects of stock-related compensation plans.*

6.3 Incentives linked to sales

In our oligopoly supergame owners can enforce tacit agreements to restrict output. Because in collusive equilibria output is given by the tacit agreement, colluding owners cannot gain strategic advantages (such as reductions in competing firms' output) by delegating control to managers under aggressive FJS-type incentives linked to sales revenue. Incentives linked to sales, though, may still play a role since they may affect owners' gains from deviations and payoffs in the punishment phase.

Consider the case analyzed in Section 5, with explicit managerial contracts of any time-length T , and suppose owners can also choose FJS-type incentive schemes linear in profits and sales. In Step 1 of any stage game an owner who expects other owners to choose pro-collusive stock-based managerial incentives may wish to deviate by choosing an aggressive FJS-type managerial contract increasing with sales. In the remainder of the supergame collusion would not be sustained, but the

deviating owner would enjoy Stackelberg profits π_i^S for the first T periods after the deviation, and of course $\pi_i^S > \pi_i^N$. Clearly, when $\pi_i^S < \pi_i^M$ the joint monopoly outcome is still supportable in equilibrium, since if owners expect other owners to follow a strategy profile prescribing the choice of stock-related incentives that lead managers to support the joint monopoly agreement, they lose strictly by deviating and choosing aggressive FJS-type incentives, whatever T and δ are. More generally, whether π_i^S is $>$, $=$, or $<$ than π_i^M , any agreement to delegate control to managers under stock-related incentives leading to a collusive outcome with per-period profits π_i^A remains supportable as long as $\pi_i^A > (1 - \delta^T)\pi_i^S + \delta^T \pi_i^{FJS}$, where π_i^{FJS} denotes profits at the Nash equilibrium of the FJS delegation game and $\pi_i^{FJS} < \pi_i^N$.¹² For small enough T this condition is satisfied even for less profitable agreements, since the owners' short-run gains from deviation generated by the opportunity to choose FJS-type incentives (first member at the RHS) are outweighed by the lower profits they induce during the subsequent non-cooperative phase (second member on the RHS).

Finally, if owners can choose “collusive” stock-based incentives and “aggressive” FJS-type incentives simultaneously, collusion can be further stabilized. To see this, consider a duopoly and the possibility of such “mixed” compensation contracts. Suppose the incentive part I_i of a manager's per-period compensation can be composed of a FJS-type incentive scheme linear in per-period profits and in sales revenue (denoted by S_i), plus an additional stock-related bonus plan as in the previous sections. That is,

$$I_i = \rho_i (\alpha_i \pi_i + (1 - \alpha_i) S_i) + (1 - \rho_i) IC_i(P_i),$$

where $IC_i(P_i)$ can be chosen from the classes defined in Sections 3 and 4. Let α^{FJS} denote the Nash equilibrium level of the parameter α in the classical FJS two-stage duopoly model. We get immediately the following result.

Proposition 7 *Even when $\pi_i^S > \pi_i^M$, and whatever T and δ are, any collusive agreement A delivering per-period profits π_i^A and satisfying (4) can be implemented by a mixed managerial contract with $\alpha = \alpha^{FJS}$, $IC_i(P_i) = ICA^L$, $\underline{P}_i > \pi^{FJS}$, and $0 < \rho < 1$.*

A formal proof would be analogous to that of Proposition 6 but is not needed, the logic behind the proposition being straightforward. The pro-collusive effect of stock options identified in Section 3.3 remains when these are part of a more complex managerial incentive scheme. In addition, when owners use the mixed contract described above, if in Step 1 of a stage game an owner deviates by setting $\rho_i = 1$,

¹²It is $\pi_i^{FJS} < \pi_i^N$ because with quantity competition, attempts to gain a strategic advantage through precommitment offset one another (see Fershtmann and Judd, 1987; or Sklivas, 1987).

the competing manager reacts already in Step 2 by maximizing the FJS-type part of his incentive scheme only, as his options are valueless whatever he does. Then, already from Step 2, instead of π_i^S the deviating manager obtains π_i^{FJS} . Therefore this mechanism, which is reminding of the one in Reitman (1993), further stabilizes collusion by ensuring that a deviating owner incurs a direct loss in the same period in which he deviates.

6.4 Demand uncertainty

Many contributions to the literature on managerial incentives in oligopoly emphasize results obtained with demand uncertainty, both because uncertainty makes the model more realistic and because it leaves room for a role for managers. The managers' task is then to observe the realization of demand, which occurs after the delegation phase, and choose output using that information (e.g. Fershtman and Judd, 1987; Reitman, 1993).

Let θ denote the stochastic component of demand, and assume θ to be independently and identically distributed in time and its distribution to be common knowledge among agents. As in Julio Rotemberg and Garth Saloner's (1986) model, with demand uncertainty the expected losses from the punishment phase that disciplines the collusive agreement are constant in time, while short-run gains from deviation change together with the realization of the state of the world θ . Then, when the discount factor binds, most profitable collusive agreements must be conditioned on the per-period realization of the shock θ . Whether the supergame is played by owners or by managers, players can agree on a "collusive rule" $q^A(\theta) = (q_1^A(\theta), \dots, q_n^A(\theta))$ mapping states of the world into firms' collusive output levels, and eventually into profits. The rule can be chosen to ensure, given agents' discount factor and the expected punishment for deviations, that for each realization of θ the prescribed collusive output levels are such that the incentive constraint is satisfied for all players. Such rule will prescribe larger collusive output levels in good states of the world, when gains from deviations are larger. It is simple to check that in our model the introduction of demand uncertainty leaves the results unchanged. Of course, demand uncertainty adds to strategic uncertainty from the ex-ante point of view, so that we must substitute $\pi_i^N, \pi_i^A, \hat{\pi}_i^A, \pi_i^M, \dots$ etc., with the corresponding expected values $E\theta [\pi_i^N(\theta)], E\theta [\pi_i^A(\theta)], E\theta [\hat{\pi}_i^A(\theta)], E\theta [\pi_i^M(\theta)], \dots$ etc., in agents' incentive constraints. Also, when owners use stock options they will now choose a strike price conditional on the state of demand $\underline{P}_i(\theta)$, if θ can be contracted upon, or otherwise keep \underline{P}_i below $\min_{\theta} \{\pi_i^M(\theta)\}$ in order to make collusion supportable in all states of demand. However, the logic behind our results goes through.

6.5 Alternative punishment strategies

We assumed that firms sustain collusive agreements by the threat of reverting to the static Nash equilibrium of the oligopoly game forever. Unrelenting trigger strategies are widely used in the literature because they satisfy the requirement of subgame perfection and they are easy to handle (both for researchers in models and for firms in markets). However, this kind of punishment is not optimal in repeated Cournot oligopolies (Abreu, 1986), and may be subject to ex-post renegotiation, which can undermine their credibility (e.g. Joseph Farrell and Maskin, 1989; Douglas Bernheim and Debraj Ray, 1989).

It is easy to check that the results continue to hold when the threat used to enforce collusion is to revert to the static Nash equilibrium only for a finite number of periods, for example because the strength of the punishment is bounded by some finite costs of renegotiation (as in Barbara McCutcheon, 1997; see also Andreas Blume, 1994).

More generally, the results concerning deferred stock-related incentives depend on managers being unable to capture any short-run gains from deviation. Therefore, all the results in Section 4 apply independent of what punishment strategies are used.¹³

What if managers have contracts in the class ICA or ICA^P and there are no renegotiation costs? In Appendix 2 we analyze the case of long-term stock-option plans and find that the results in Section 3 can be extended both to the case of Abreu's (1986) two-phase optimal punishments and to that of Eric van Damme's (1989) "repentance" renegotiation-proof strategies.

6.6 Renegotiation of managerial contracts

In the introduction we argued that stock-related incentives are less subject than other types of incentive to secret renegotiation, because they require shareholders' approval which is given in public shareholders' meetings. If this were not the case, the results of the model would still be of interest for several reasons.

¹³Even in the case of ICC-type incentives, for which there is the chance that a punishment phase of finite length has passed at the time when the incentives are paid, the pro-collusive effect is independent of the shape of the punishment phase as long as the date at which the manager leaves the firm is uncertain. Of course if the punishment phase lasts one period only, as in Abreu's (1986) two-phase optimal punishments, and the ICC-type incentive is deferred for more than one period with certainty, then neither a deviation nor the punishment affect manager's compensation, and we are led to owners' incentive compatibility condition (condition (1), amended for the new punishment) by assumption 3 in Section 2.3. However, in this case owners can simply choose incentives in the classes ICA and ICB.

Even if we assume concentrated ownership, so that public shareholders' meetings are not required to renegotiate managers' compensation, the *cost* of renegotiation may be substantial for owners; and renegotiation costs give commitment value to managerial incentives. There will typically be direct costs of the bilateral bargaining process between managers and owners, even if there are no information asymmetries (Luca Anderlini and Leonardo Felli, 1998). When third parties (for example debtholders) have seats on the board, the bargaining process becomes trilateral and bargaining costs increase. Moreover, interlocked directors and large finance-providers with industry-wide interests will oppose any renegotiation of managerial contract that leads to a market war (Spagnolo, 1996, 1998).

Finally, suppose secret renegotiation were possible and costless. The results would still be of substantial interest. Many economists believe that the incentive compatibility conditions for tacit collusion, inequality (1) in our model, are easily satisfied in most real-world oligopolistic industries (e.g. Carl Shapiro, 1989). If this is true, then if tacit collusion is not present in *all* mature oligopolistic industries it is only because of coordination failures.¹⁴ In this case, owners would not want to renegotiate managers' contracts, and the pro-collusive effects of delegation with stock-related managerial incentives would be to further stabilize tacit collusion and facilitate coordination.¹⁵

7 Concluding remarks

We are not arguing here that the effects of stock-related compensation plans on firms' ability to collude is the only or the main force driving their adoption. As in most previous work on the strategic effects of delegation, to make the model tractable we had to abstract from many important issues, particularly from that of managerial moral hazard (just as most of the literature on moral hazard abstracts from the strategic effects of incentive contracts). When managers' moral hazard is brought into the picture many other beneficial effects of these incentives emerge.

However, we believe that in the imperfectly competitive real world, the pro-collusive effect of these incentives may be one reason behind their success. In the end, shareholders are satisfied when their managers' incentive schemes lead to higher

¹⁴Fines from competition authorities seem much too small to deter collusion (e.g. McCutcheon, 1997).

¹⁵For example, moderately high strike-prices for managers' stock options restrict the set of supportable collusive agreement to the more profitable ones. Moreover, CEOs have typically a more homogeneous background than shareholders, they are professionals with similar educations and careers, and a common background is the best known among the factors that facilitate coordination (e.g. Thomas Schelling, 1960).

stock prices, regardless of whether this is achieved through higher effort or more effective collusion.

8 Appendices

8.1 Appendix 1: Proofs

Proof of Lemma 1 When profits increase (decrease) in one period and everything else remains equal, the stock price increases (decreases) too. Therefore – with regard to the stage game – the stock price function is a monotone transformation of the profit function. A managerial compensation function increasing with the stock price is a further monotone transformation of the profit function; consequently, managers' objective function is a monotone transformation of owners' objective function. The set of Nash equilibria of a game is not affected by monotone transformations of the payoff functions, since these generate ordinally equivalent games. The statement follows. **Q.E.D.**

Proof of Proposition 1 At $\delta = \underline{\delta}^A$ condition (1) is satisfied as an equality and

$$\frac{\pi_i^A}{1 - \underline{\delta}^A} = \hat{\pi}_i^A + \frac{\underline{\delta}^A}{1 - \underline{\delta}^A} \pi_i^N, \implies \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right) = \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\underline{\delta}^A}{1 - \underline{\delta}^A} \pi_i^N \right).$$

Substituting from the last equality into (2) we obtain

$$\frac{1}{1 - \underline{\delta}^A} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right) \right] + \frac{\underline{\delta}^A}{1 - \underline{\delta}^A} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \underline{\delta}^A} \right) \right],$$

which after a few algebraic manipulations becomes

$$f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \underline{\delta}^A} \right) \right],$$

which is always satisfied. Because the inequality is strict, by continuity, perturbing the discount factor around $\underline{\delta}^A$ we can find a continuum of discount factors lower than $\underline{\delta}^A$ at which such a condition is satisfied but (1) is not. This reasoning applies to any stationary collusive agreement A and to each firm i . Statement (i) follows.

Conversely, given agents' discount factor, at the most collusive agreement that owners can support, delivering $\pi_i^{\bar{A}}$, we have $\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1 - \delta} \right) = \frac{1}{\varphi_i} \left(\hat{\pi}_i^{\bar{A}} + \frac{\delta}{1 - \delta} \pi_i^N \right)$, and substituting into condition (2) we obtain

$$\frac{1}{1 - \delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1 - \delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1 - \delta} \right) \right] + \frac{\delta}{1 - \delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \delta} \right) \right],$$

that leads to

$$f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \right],$$

which is always true. By continuity, perturbing profits around $\pi_i^{\bar{A}}$ we can find a continuum of higher collusive profit streams which satisfy this condition but not condition (1). This reasoning applies to any stationary collusive agreement and to each firm i . Statement (ii) follows. **Q.E.D.**

Proof of Proposition 2 Substituting for stock prices into (4) we obtain

$$\frac{1}{1-\delta} \frac{\alpha_i K}{\varphi_i} \frac{\pi_i^A}{1-\delta} > \alpha_i \frac{\hat{\pi}_i^A + \delta \frac{K \pi_i^N}{1-\delta}}{\varphi_i \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)} + \frac{\delta}{1-\delta} \frac{\alpha_i K}{\varphi_i} \frac{\pi_i^N}{1-\delta},$$

or, equivalently,

$$\frac{\pi_i^A}{1-\delta} > \frac{(1-\delta) \left(\hat{\pi}_i^A + \delta \frac{K \pi_i^N}{1-\delta} \right)}{K \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)} + \frac{\delta \pi_i^N}{1-\delta}.$$

This inequality is less stringent than (1), so that it is satisfied at $\delta < \underline{\delta}^A$ and at $\pi^A > \pi^{\bar{A}}$ and the statements hold, if

$$\frac{(1-\delta) \left(\hat{\pi}_i^A + \delta \frac{K \pi_i^N}{1-\delta} \right)}{K \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)} < \hat{\pi}_i^A,$$

or, equivalently, if

$$\frac{\delta \pi_i^N}{\left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)} < \hat{\pi}_i^A - \frac{(1-\delta) \hat{\pi}_i^A}{K \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right)},$$

which reduces to

$$\delta \pi_i^N < \hat{\pi}_i^A \left(1 + \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \right) - (1-\delta) \hat{\pi}_i^A \frac{\varphi_i (1-\delta) + \frac{\alpha_i}{\varphi_i}}{\varphi_i (1-\delta)},$$

and to

$$\delta \pi_i^N < \hat{\pi}_i^A + \hat{\pi}_i^A \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} - \hat{\pi}_i^A (1-\delta) - \hat{\pi}_i^A \frac{1}{\varphi_i} \frac{\alpha_i}{\varphi_i} \Rightarrow \pi_i^N < \hat{\pi}_i^A,$$

which is always true. **Q.E.D.**

Proof of Proposition 3 Manager i 's incentive compatibility constraint is (5). Evaluating (1) at $\delta = \underline{\delta}^A$ we obtain

$$\frac{\pi_i^A}{1-\underline{\delta}^A} = \hat{\pi}_i^A + \frac{\underline{\delta}^A}{1-\underline{\delta}^A} \pi_i^N, \implies \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\underline{\delta}^A} \right) = \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\underline{\delta}^A}{1-\underline{\delta}^A} \pi_i^N \right).$$

Substituting from this equality into (5) and simplifying we obtain

$$\gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right) - \underline{P}_i \right] > \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \underline{\delta}^A} \right) - \underline{P}_i \right], 0 \right\}.$$

By inspection, for any strike price $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right)$ and number of options $\gamma_i \neq 0$ this condition holds as a *strict* inequality. By continuity, perturbing the discount factor around $\underline{\delta}^A$ we can find a continuum of discount factors lower than $\underline{\delta}^A$ (of more collusive agreement, i.e., $\pi_i \geq \pi_i^A$) at which such a condition is satisfied but (1) is not. This reasoning applies to any stationary collusive agreement A and to each firm i . This proves statement (i).

Conversely, given the discount factor, at the most collusive agreement owners can support, delivering firm profits $\pi_i^{\bar{A}}$, we have $\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1 - \delta} \right) = \frac{1}{\varphi_i} \left(\hat{\pi}_i^{\bar{A}} + \frac{\delta}{1 - \delta} \pi_i^N \right)$, and substituting into (3') and simplifying we obtain

$$\gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^{\bar{A}}}{1 - \delta} \right) - \underline{P}_i \right] > \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \delta} \right) - \underline{P}_i \right], 0 \right\},$$

which holds as a strict inequality for any $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}^A} \right)$ and $\gamma_i \neq 0$. By continuity, perturbing profits around $\pi_i^{\bar{A}}$ we can find a continuum of collusive profit streams which satisfy this condition but not condition (1). This line of reasoning applies to any stationary collusive agreement and to each firm i . Statement (ii) follows. **Q.E.D.**

Proof of Corollary 1: Consider first the case $\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1 - \delta} \right) \leq \underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \delta} \right)$. Condition (5) becomes

$$\frac{1}{1 - \delta} \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \delta} \right) - \underline{P}_i \right] > \gamma_i \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1 - \delta} \right) - \underline{P}_i \right],$$

or, equivalently,

$$\delta \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1 - \delta} \right) - \underline{P}_i \right] > \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1 - \delta} \right) - \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \delta} \right).$$

Then, a manager under an ICA^P-type contract with strike price \underline{P}_i is willing to support any given collusive agreement A as long as

$$\delta > \underline{\delta}_{ICA^P}^A = \frac{\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta_{ICA^P}^A \pi_i^N}{1 - \delta_{ICA^P}^A} \right) - \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \delta_{ICA^P}^A} \right)}{\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta_{ICA^P}^A \pi_i^N}{1 - \delta_{ICA^P}^A} \right) - \underline{P}_i}.$$

By inspection, $\underline{\delta}_{ICAP}^A$ is independent of γ_i and is increasing with \underline{P}_i . Analogously, the upper bound of the collusive profit streams supportable by a manager under $ICAP$ -type contracts is $\pi_i^{\overline{ICAP}}$, where

$$\frac{1}{\varphi_i} \left(\frac{\pi_i^{\overline{ICAP}}}{1-\delta} \right) - (1-\delta) \frac{1}{\varphi_i} \left(\widehat{\pi}_i^{\overline{ICAP}} + \frac{\delta \pi_i^N}{1-\delta} \right) = \delta \underline{P}_i.$$

Take the upper bound $\pi_i^{\overline{ICAP}'}$ which satisfies the equality above at a given strike price \underline{P}_i' . A reduction in \underline{P}_i makes the condition satisfied as a strict inequality, moving the upper bound to a higher profit level. So $\pi_i^{\overline{ICAP}}$ is a decreasing function of \underline{P}_i .

Consider now the case of $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right)$. The incentive compatibility condition becomes

$$\begin{aligned} \frac{1}{1-\delta} \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) - \underline{P}_i \right] &> \gamma_i \left[\frac{1}{\varphi_i} \left(\widehat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) - \underline{P}_i \right] + \\ &+ \frac{\delta}{1-\delta} \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) - \underline{P}_i \right]. \end{aligned}$$

The minimum level of the discount factor at which the manager can support collusion becomes

$$\underline{\delta}_{ICAP}^A = \frac{\frac{1}{\varphi_i} \left(\widehat{\pi}_i^A + \frac{\delta^A}{1-\delta^A} \pi_i^N \right) - \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta^A} \right)}{\frac{1}{\varphi_i} \left(\widehat{\pi}_i^A + \frac{\delta^A}{1-\delta^A} \pi_i^N \right) - \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta^A} \right)},$$

and the condition that identifies the most collusive agreement supportable at the given discount factor $\pi_i^{\overline{ICAP}}$ becomes

$$\frac{1}{\varphi_i} \left(\frac{\pi_i^{\overline{ICAP}}}{1-\delta} \right) = (1-\delta) \frac{1}{\varphi_i} \left(\widehat{\pi}_i^{\overline{ICAP}} + \frac{\delta \pi_i^N}{1-\delta} \right) + \delta \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right).$$

The last two equalities are both independent of γ_i and \underline{P}_i . All this holds for every firm i and the statement follows. **Q.E.D.**

Proof of Proposition 4: Consider first the class ICB. The incentive compatibility condition for a stationary collusive agreement A to be respected by the manager of firm i under ICB-type contracts is

$$\frac{1}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right) \right] + \frac{\delta}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right) \right],$$

or, equivalently,

$$f_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right) \right],$$

which is *always* satisfied, at any discount factor δ , agreement A , and firm i .

Consider now contracts in the class ICC. The expected flow of earnings for the manager of firm i in any period t in which he is running the firm is

$$\delta(1-\eta)(1+r)f_i(P_i^{t+1}) + \delta^2\eta(1-\eta)(1+r)^2f_i(P_i^{t+2}) + \delta^3\eta^2(1-\eta)\gamma_i(1+r)^3f_i(P_i^{t+3}) + \dots,$$

which reduces to

$$(1-\eta)\gamma_i \sum_{\tau=1}^{\infty} \eta^{\tau-1} f_i(P_i^{t+\tau}).$$

As long as the manager sticks to a stationary collusive agreement delivering per period profits π_i^A we have $P_i^{t+\tau} = \frac{1}{\varphi_i} \left(\frac{1}{1-\delta} \pi_i^A \right) \forall \tau > 0$. If the manager deviates in any period t we have $P_i^{t+\tau} = \frac{1}{\varphi_i} \left(\frac{1}{1-\delta} \pi_i^N \right) \forall \tau > 0$. Because $\frac{1}{\varphi_i} \left(\frac{1}{1-\delta} \pi_i^A \right) > \frac{1}{\varphi_i} \left(\frac{1}{1-\delta} \pi_i^N \right)$ is always satisfied, whatever the discount factor δ the manager always finds it convenient not to deviate from the agreement. This applies to any agreement A and firm i , and the statement follows. **Q.E.D.**

Proof of Proposition 5: Consider first the class ICB^P . The incentive compatibility condition for a stationary collusive agreement A to be respected by the manager of firm i under ICB^P -type contracts becomes

$$\begin{aligned} \frac{1}{1-\delta} \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right) - \underline{P}_i \right], 0 \right\} &> \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right) - \underline{P}_i \right], 0 \right\} + \\ &+ \frac{\delta}{1-\delta} \max \left\{ \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right) - \underline{P}_i \right], 0 \right\}, \end{aligned}$$

or, equivalently,

$$\begin{cases} \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right) > \underline{P}_i, & \text{for } \underline{P}_i \geq \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right), \\ \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right) > \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right), & \text{for } \underline{P}_i \leq \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^N}{1-\delta} \right). \end{cases}$$

Because $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\delta \pi_i^A}{1-\delta} \right)$ this condition is *always* satisfied. This holds at any discount factor, for any agreement A , and for every firm i .

Consider now contracts in the class ICC. The amount of stock options given to a manager who stops working for the firm τ periods after he started is $\gamma_i(1+r)^\tau$. The expected flow of earnings for the manager of firm i in any period t in which he is running the firm is then

$$\delta(1-\eta)\gamma_i(1+r)(P_i^{t+1} - \underline{P}_i) + \delta^2\eta(1-\eta)\gamma_i(1+r)^2(P_i^{t+2} - \underline{P}_i) + \dots,$$

which reduces to

$$(1-\eta)\gamma_i \sum_{\tau=1}^{\infty} \eta^{\tau-1} (P_i^{t+\tau} - \underline{P}_i).$$

As long as the manager sticks to a stationary collusive agreement delivering per period profits π_i^A we have $P^{t+\tau} = \frac{1}{\varphi_i} \left(\frac{1}{1-\delta} \pi_i^A \right) \forall \tau > 0$. As long as $\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \leq \underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right)$, manager i 's expected payoff function reduces to

$$\begin{cases} \gamma_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) - \underline{P}_i \right] & \text{if } q_i^t \leq q_i^A \quad \forall t < \tau, \\ 0 & \text{otherwise.} \end{cases}$$

Therefore, whatever the discount factor δ , the manager always finds it convenient not to deviate from the agreement. This applies to any agreement A and firm i . The statement follows. **Q.E.D.**

Proof of Proposition 6: Consider the following strategy profile for the delegation supergame.

Each owner's strategy: "*Delegate control to a manager under a stock-related explicit contract among those defined in Sections 3 and 4, of finite length T , such that if the same contract had infinite length (if $T \rightarrow \infty$) the manager would be willing to support the collusive agreement A delivering per-period profits π_i^A , and such that at least at this collusive equilibrium the manager is paid above his reservation wage; at the beginning of each of the following stage games (in periods $t+T$, $t+2T$, etc.), reconfirm the manager and the contract for one more stage if all other owners have done so in the past and no manager has ever deviated from equilibrium strategies; hire a profit-maximizing manager at his reservation wage forever otherwise.*

Each manager's strategy: "*Respect the collusive agreement A at all steps of each stage game as long as all owners have delegated/reconfirmed managers with the incentive contracts described above in each past stage game and no manager has ever deviated from the collusive agreement; maximize the firm's static profits forever otherwise.*"

Let us check for unilateral deviations to see whether this strategy profile is a subgame-perfect equilibrium independently of the length of the managerial contracts and of the discount factor.

Owners: In Step 1 of each stage game an owner can choose to deviate unilaterally from the equilibrium strategy profile by breaking the implicit contract and replacing the manager, by choosing a profit-based incentive contract, or both. However the owner deviates, and whatever T and δ are, the deviation is observed by the managers of the competing firms who, following equilibrium strategies, start maximizing firms' profits already from Step 2. Therefore, owners' expected payoff from deviating is a discounted flow of Cournot Nash profits. It follows that owners lose strictly by deviating unilaterally from the strategy profile above, whatever the length of the contract and the discount factor are.

Managers: Managers can deviate from equilibrium in any step after the first of each stage game. Whatever T and δ are, if a manager has a contract in the class ICB, ICC, ICB L or ICC L , he gains nothing by deviating because short-run profits are distributed before he gets his stock-related bonuses (see proofs of Propositions 4 and 5). If the manager has a contract in the class ICA or ICA L , in the period in which he deviates his stock-related bonus does increase in value. However, starting from the following period other managers maximize static firm profits and the value of his stock-related bonus falls. And at the end of the stage game in which he deviated he is fired, so in all periods after that stage game he receives only his reservation wage, which we can normalize to zero with no loss of generality. It follows that the most profitable deviation is the one that occurs in Step 2 of a stage game. Consider the case of ICA contracts. If explicit contracts are of any finite length T , a manager's no deviation condition is

$$\frac{1}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) \right] + \frac{\delta(1-\delta^{T-1})}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \right].$$

Because for any finite T and at any δ it holds $\frac{\delta(1-\delta^{T-1})}{1-\delta} < \frac{\delta}{1-\delta}$, the RHS of this condition is smaller than the RHS of condition (2), and the condition is always satisfied when (2) is. Since equilibrium strategies prescribe owners to use stock-related explicit contracts such that for $T \rightarrow \infty$ the manager would be willing to support the collusive agreement, if in equilibrium managers have ICA-type contracts condition (2) must be satisfied, and so will be the inequality above. The same reasoning holds when owners choose a contract in the class ICA L . The statement follows. **Q.E.D.**

Proof of Corollary 2: Consider the case of managers under ICA contracts of length T , and maintain the previous proof's normalization of managers' reservation wage to zero. The managers will stick to an agreement A as long as the inequality in the proof of Proposition 6 holds:

$$\frac{1}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \right] > f_i \left[\frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) \right] + \frac{\delta(1-\delta^{T-1})}{1-\delta} f_i \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \right].$$

Because $\frac{\delta(1-\delta^{T-1})}{1-\delta}$ is increasing in T , the RHS of the inequality is increasing in T . It follows that the condition becomes more stringent the larger T is. Analogous reasoning holds for contracts in the class ICA L with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) \forall i$. **Q.E.D.**

Profit-sharing: Suppose owners can choose the parameters α_i , γ_i and \underline{P}_i of a managerial compensation package $I_i = \alpha_i \pi_i + (1-\alpha_i) \gamma_i \max \left\{ \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) - \underline{P}_i, 0 \right\}$.

We show here that it is a dominant strategy for each owner to maximize managers' ability to support collusive agreements by choosing $\alpha_i = 0$.

Let us normalize the parameters and restrict attention to the case in which $\gamma_i = (1 - \alpha_i)$ and $\alpha_i \leq 1$, which encompasses all economically relevant cases. Under such a contract, the incentive compatibility condition for a stationary collusive agreement A to be respected by the manager of firm i with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right)$ becomes

$$\begin{aligned} \frac{1}{1-\delta} \left\{ \alpha_i \pi_i^A + (1-\alpha_i) \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) - \underline{P}_i \right] \right\} &\geq \\ &\geq \alpha_i \hat{\pi}_i^A + (1-\alpha_i) \max \left\{ \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) - \underline{P}_i, 0 \right\} + \\ &\quad + \alpha_i \frac{\delta \pi_i^N}{1-\delta} + (1-\alpha_i) \frac{\delta \max \left\{ \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) - \underline{P}_i, 0 \right\}}{1-\delta}, \end{aligned}$$

which can be rearranged into

$$\begin{aligned} (1-\alpha_i) \left\{ \frac{\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) - \underline{P}_i}{1-\delta} - \max \left\{ \frac{1}{\varphi_i} \left(\hat{\pi}_i^A + \frac{\delta \pi_i^N}{1-\delta} \right) + \underline{P}_i, 0 \right\} + \right. \\ \left. - \frac{\delta \max \left\{ \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right) - \underline{P}_i, 0 \right\}}{1-\delta} \right\} + \alpha_i \left\{ \frac{\pi_i^A}{1-\delta} - \hat{\pi}_i^A - \frac{\delta \pi_i^N}{1-\delta} \right\} &\geq 0. \quad (6) \end{aligned}$$

It is evident that condition (6) is a linear combination of conditions (1) and (3), with α_i and $(1 - \alpha_i)$ as weights. If owners decide to delegate, they can choose the value of two parameters in their managers' compensation package, α_i and \underline{P}_i . Given a level of \underline{P}_i , when $\alpha_i = 1$ managers have exactly the same incentives as owners (only condition (1) matters), and when $\alpha_i = 0$ we are in the case of Section 3.2.

Evaluating condition (6) at the most collusive profit stream which profit-maximizing managers or owners can sustain, we obtain that the first term of the LHS is strictly positive (by the Proof of Proposition 1) and the second is zero (by definition). This means that as long as $\alpha_i < 1$, condition (6) is satisfied as a strict inequality and managers under this mixed contract can support more collusive agreements than profit-maximizing managers. However, because the second term on the LHS is negative, as long as $\alpha_i > 0$ managers under ICA-type contracts will still be able to support more collusive agreements. In the Proof of Corollary 1 we have shown that the member within the first graph parentheses on the LHS of (6) is *always* larger than the content of the second graph parentheses. It follows that owners maximize managers' ability to support collusive agreements by choosing $\underline{P}_i \leq \frac{1}{\varphi_i} \left(\frac{\pi_i^N}{1-\delta} \right)$

and $\alpha_i = 0$. Because contracts are observable, managers collude only if all owners delegate under suitable incentive contracts, and can react if an owner deviates from the agreed strategies. Because owners cannot lose by delegating control, while they gain strictly when more profitable collusive agreements become supportable in equilibrium, each owner's dominant strategy is to set $\alpha_i = 0$. **Q.E.D.**

8.2 Appendix 2: Alternative punishment strategies

8.2.1 Optimal punishments

The results of Section 3 can be extended to the case in which players use two-phase optimal punishment strategies (Abreu, 1986). Consider the case of stock options.

Proposition 8 *When the repeated oligopoly game is played by managers under ICA^P-type contracts with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \forall i$, then the minimum discount factor at which any collusive agreement delivering per-period profits π_i^A can be supported in subgame-perfect equilibrium by two-phase symmetric optimal punishments (as defined in Abreu, 1986) is strictly lower (and, for a given discount factor, more profitable collusive agreements become supportable) than when firms are led by profit-maximizing managers.*

Proof: By Theorem 15 in Abreu (1986), producing for one period a symmetric vector $q^{PA} > q^N$ delivering profits $\pi_i^{PA} = \pi_i(q^{PA})$, with $\pi_i^{PA} < \pi_i^N < \pi_i^A$, and then going back to the collusive output is an optimal two-phase symmetric punishment. The punishment is able to support a symmetric stationary collusive agreement A to restrict production to the vector q^A if the system

$$\begin{cases} \delta(\pi_i^A - \pi_i^{PA}) = \hat{\pi}_i^{PA} - \pi_i^{PA} \\ \hat{\pi}_i^A - \pi_i^A \geq \delta(\pi_i^A - \pi_i^{PA}), \end{cases} \quad (\text{OP})$$

is satisfied, where as usual $\hat{\pi}_i^{PA} = \pi_i(\hat{q}_i(q_{-i}^{PA}), q_{-i}^{PA})$ are firm i 's profits from deviating from the prescribed punishment path and choosing a best response to other firms' output vector q_{-i}^{PA} .

Denote by $\underline{\delta}_{OP}^A$ the minimum level of the discount factor at which profit-maximizing managers can support the collusive agreement A using a symmetric two-stage optimal punishment. This level is defined by the equality

$$\hat{\pi}_i^A - \pi_i^A = \underline{\delta}_{OP}^A (\pi_i^A - \pi_i^{PA}) = \hat{\pi}_i^{PA} - \pi_i^{PA}.$$

By Theorems 14 and 18 in Abreu (1986), the symmetric two-stage punishment strategy which delivers profits $\pi_i^{PA} < \pi_i^N$ for one period after a deviation and then

reverts to the collusive agreement A is the unique symmetric optimal punishment; further, it is a globally optimal punishment if $\underline{\delta}_{OP}^A$ is not too low. From the definition of $\underline{\delta}_{OP}^A$ we have

$$\widehat{\pi}_i^A - \pi_i^A = \underline{\delta}_{OP}^A(\pi_i^A - \pi_i^{PA}),$$

or, equivalently,

$$\frac{\underline{\delta}_{OP}^A{}^2 \pi_i^A}{1 - \underline{\delta}_{OP}^A} + \widehat{\pi}_i^A - \pi_i^A = \underline{\delta}_{OP}^A(\pi_i^A - \pi_i^{PA}) + \frac{\underline{\delta}_{OP}^A{}^2 \pi_i^A}{1 - \underline{\delta}_{OP}^A},$$

that simplifies to

$$\frac{\pi_i^A}{1 - \underline{\delta}_{OP}^A} = \widehat{\pi}_i^A + \underline{\delta}_{OP}^A \pi_i^{PA} + \frac{\underline{\delta}_{OP}^A{}^2 \pi_i^A}{1 - \underline{\delta}_{OP}^A}. \quad (7)$$

Consider now managers' incentive compatibility constraint to support the joint monopoly agreement under ICA when optimal two-phase punishments are used and the discount rate is $\underline{\delta}_{OP}^A$. First we check that these strategies are subgame-perfect also for these managers. With $\gamma_i = 1$ in the period after a deviation, if a manager sticks to the agreed strategies he expects discounted payoffs

$$\begin{aligned} S^{OP} = & \max \left\{ \frac{1}{\varphi_i} \left(\pi_i^{PA} + \frac{\underline{\delta}_{OP}^A \pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i, 0 \right\} + \\ & + \frac{\underline{\delta}_{OP}^A}{1 - \underline{\delta}_{OP}^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i \right]. \end{aligned}$$

If he deviates and causes the other manager to restart the punishment phase he expects

$$\begin{aligned} D^{OP} = & \max \left\{ \frac{1}{\varphi_i} \left(\widehat{\pi}_i^{PA} + \underline{\delta}_{OP}^A \pi_i^{PA} + \frac{\underline{\delta}_{OP}^A{}^2 \pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i, 0 \right\} + \\ & + \underline{\delta}_{OP}^A \max \left\{ \frac{1}{\varphi_i} \left(\pi_i^{PA} + \frac{\underline{\delta}_{OP}^A \pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i, 0 \right\} + \\ & + \frac{\underline{\delta}_{OP}^A{}^2}{1 - \underline{\delta}_{OP}^A} \left\{ \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i \right\}, \end{aligned}$$

and $S^{OP} - D^{OP} = 0$ by the definition of owners' optimal punishment (OP). So managers have no incentives to deviate ex post.

Now, with owners' optimal punishment strategies, managers' incentive compatibility condition becomes

$$\frac{1}{1 - \underline{\delta}_{OP}^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i \right] \geq$$

$$\begin{aligned}
&\geq \max \frac{1}{\varphi_i} \left\{ \left(\hat{\pi}_i^A + \underline{\delta}_{OP}^A \pi_i^{PA} + \frac{\underline{\delta}_{OP}^A{}^2 \pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i, 0 \right\} \\
&\quad + \underline{\delta}_{OP}^A \max \left\{ \frac{1}{\varphi_i} \left(\pi_i^{PA} + \frac{\underline{\delta}_{OP}^A \pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i, 0 \right\} \\
&\quad + \frac{\underline{\delta}_{OP}^A{}^2}{1 - \underline{\delta}_{OP}^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_{OP}^A} \right) - \underline{P}_i \right].
\end{aligned} \tag{8}$$

By equality (7) the first term in squared brackets on the RHS of (8) equals the content of the square brackets in the term at the LHS and in the third term at the RHS of (8), and is strictly larger than the content of the squared bracket in the second term at the RHS of (8). It follows that (8) is satisfied as a strict inequality and, by continuity, there will be a sequence of discount factors lower than $\underline{\delta}_{OP}^A$ at which (8) is still satisfied. This applies to any firm i and collusive agreement A . For a fixed δ the same line of reasoning proves that the set of supportable collusive agreements is larger for managers under ICA-type incentives when optimal two-phase punishments are used. For incentives linear in stock price, substitute $\underline{P}_i = 0$ and note that the reasoning above continues to hold. The statement follows. **Q.E.D.**

The intuition is analogous to that behind Propositions 1 to 3. The only difference is that here the negative effect of the punishment is concentrated in the period immediately following the deviation.

8.2.2 Renegotiation-proof strategies

Consider the case in which firms use renegotiation-proof strategies (in the sense of Farrell and Maskin, 1989). For simplicity, let us focus on a duopoly ($i \in \{1, 2\}$), so that we can consider renegotiation-proof punishment strategies of the kind proposed by van Damme (1989) for the repeated Prisoner's Dilemma. In our Cournot model, these strategies can be defined as follows:

Punishment strategies “R”:

Phase 1: Stick to the collusive output level as long as the other firm did the same in the past; if the other firm deviates, then start Phase 2;

Phase 2: Produce the full monopoly output q^M as long as the other firm's output is positive; if for (say) one period the other firm's output is zero, restart Phase 1 in the following period.¹⁶

¹⁶These strategies are weakly renegotiation-proof (and strongly renegotiation-proof for the joint monopoly collusive agreement) because after firm i deviates it is supposed to “give a premium”

Then we can state what follows.

Proposition 9 *When the repeated oligopoly game is played by managers under ICA^P-type contracts with $\underline{P}_i < \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\delta} \right) \forall i$, the minimum discount factor at which any collusive agreement delivering per-period profits π_i^A can be supported in subgame-perfect equilibrium by renegotiation-proof strategies R is strictly lower (and, for a given discount factor, more profitable collusive agreements become supportable,) than when firms are led by profit-maximizing managers.*

Proof: To support a collusive agreement in subgame-perfect equilibrium, the strategy profile must also satisfy the deviating firm's incentive constraint, that is, it must be convenient for the firm which has deviated to repent after the deviation so that

$$0 + \frac{\delta \pi_i^A}{1-\delta} \geq \frac{\pi_i(\hat{q}_i(q^M), q^M)}{1-\delta}.$$

Assume this condition is satisfied. Let $\underline{\delta}_R^A$ denote the minimum level of the discount factor at which the joint monopoly collusive agreement is supportable by profit-maximizing managers using these renegotiation-proof strategies with one-period "repentance," where – assuming $\pi_i^A \underline{\delta}_R^A \geq \pi_i(\hat{q}_i(q^M), q^M) - \underline{\delta}_R^A$ is defined by the equality

$$\frac{\pi_i^A}{1-\underline{\delta}_R^A} = \hat{\pi}_i^A + \frac{\delta^{A2} \pi_i^A}{1-\underline{\delta}_R^A}. \quad (\text{R})$$

First we check that strategies R are subgame-perfect for managers too. To economize on symbols set γ_i Set In the period after a deviation, if the manager of firm i who deviated sticks to the agreed punishment strategies R, he gets expected payoffs

$$S_i^R = \max \left\{ \frac{1}{\varphi_i} \left(\frac{\delta^{A2} \pi_i^A}{1-\underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} + \frac{\underline{\delta}_R^A}{1-\underline{\delta}_R^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1-\underline{\delta}_R^A} \right) - \underline{P}_i \right],$$

while deviating he causes the other manager to restart the punishment and obtains expected payoffs

$$D_i^R = \max \left\{ \frac{1}{\varphi_i} \left(\pi_i(\hat{q}_i(q^M), q^M) + \frac{\delta^{A2} \pi_i^A}{1-\underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} +$$

to the other firm j in order to restart cooperation. By not producing for one period, firm i earns zero profits while it makes firm j 's profits increase over the level of the joint monopoly collusive agreement. Such a premium makes it more profitable for firm j to insist on the agreed punishment strategies rather than to renegotiate them toward new collusive outcomes.

$$\begin{aligned}
& +\underline{\delta}_R^A \max \left\{ \frac{1}{\varphi_i} \left(\frac{\underline{\delta}_R^A \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} + \\
& + \frac{\underline{\delta}_R^{A2}}{1 - \underline{\delta}_R^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right].
\end{aligned}$$

Consider now the incentive not to deviate, the difference

$$\begin{aligned}
S_i^R - D_i^R = & \max \left\{ \frac{1}{\varphi_i} \left(\frac{\underline{\delta}_R^A \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} - \max \left\{ \frac{1}{\varphi_i} \left(\pi_i(\widehat{q}_i(q^M), q^M) + \frac{\underline{\delta}_R^{A2} \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} \\
& + \underline{\delta}_R^A \left\{ \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right] - \max \left\{ \frac{1}{\varphi_i} \left(\frac{\underline{\delta}_R^A \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\} \right\}.
\end{aligned}$$

The difference between the first two members on the RHS is positive because when defining R we assumed $\pi_i^A \underline{\delta}_R^A \geq \pi_i(\widehat{q}_i(\bar{q}_j), \bar{q}_j)$; the third member on the RHS is strictly positive by inspection, therefore $S_i^R - D_i^R > 0$.

On the other hand, the manager of firm j , who did not deviate, by sticking to the agreed strategies in the period after a deviation gets expected payoffs:

$$\begin{aligned}
S_j^R = & \frac{1}{\varphi_i} \left[2\pi_j^M + \frac{\underline{\delta}_R^A}{1 - \underline{\delta}_R^A} \frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right] + \\
& + \frac{\underline{\delta}_R^A}{1 - \underline{\delta}_R^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right],
\end{aligned}$$

and any deviation from R will cause him a loss.

Then, with punishment strategies R the managers' incentive compatibility condition becomes

$$\begin{aligned}
\frac{1}{1 - \underline{\delta}_R^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right] & \geq \\
& \geq \left[\frac{1}{\varphi_i} \left(\widehat{\pi}_i^A + \frac{\underline{\delta}_R^{A2} \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right], \quad (9) \\
& + \underline{\delta}_R^A \max \left\{ \frac{1}{\varphi_i} \left(\frac{\underline{\delta}_R^A \pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i, 0 \right\}, \\
& + \frac{\underline{\delta}_R^{A2}}{1 - \underline{\delta}_R^A} \left[\frac{1}{\varphi_i} \left(\frac{\pi_i^A}{1 - \underline{\delta}_R^A} \right) - \underline{P}_i \right].
\end{aligned}$$

By equality (R) the first term in squared brackets on the RHS of (9) equals the content of the squared brackets in the term on the LHS and in the third term on the RHS of (9), and is strictly larger than the content of the squared brackets in the second term on the RHS of (9). It follows that (9) is satisfied as a strict inequality and, by continuity, there will be a sequence of discount factors lower than $\underline{\delta}_R^A$ at which (9) is still satisfied. This reasoning applies to any collusive agreement other than the joint monopoly one. For incentives linear in stock price substitute $\underline{P}_i = 0$, and note that the reasoning above continues to hold. The statement follows. **Q.E.D.**

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Non-Technical Summary

The low pay-performance sensitivity of managerial compensation observed in many countries led to concerns about the welfare implications of most common governance practices, since low-powered managerial incentives tend to soften product-market competition.

The pay-performance sensitivity of U.S. top-managers' compensation has increased substantially in the last decade because of a widespread adoption of stock-related incentives, such as stock option plans. Stock-based managerial incentives are believed to have beneficial effects on managers' effort and investment choices. What about their effects on product markets? Does this trend towards stock-based incentives imply a more competitive attitude on the part of managers, so that concerns about tacit collusion and social welfare can be abandoned at least in the U.S.?

The results of this paper suggest that this may not be the case. Our model shows that as long as agents in financial markets have rational expectations and firms pay out profits as dividends, most common stock-based managerial compensation plans greatly facilitate tacit collusion in long-run oligopolies. We find that stock-related compensation reduces managers' incentives to break any tacit collusive agreement in any mature (repeated) oligopoly, and may make the joint monopoly agreement supportable at any level of the discount factor.

The reason is that the stock price incorporates additional information with respect to a firm's profits, information strictly related to the firm's future profitability. Incentive schemes based on stock price link managers' *present* compensation to the stock market's expectations about firms' *future* profitability. When a breach of a tacit collusive agreement occurs, a stock market with rational expectations anticipates the negative effect of the breach on firms' future profitability due to the forthcoming market war, and immediately discounts it on the stock price. Because this effect occurs in the very same period in which a manager deviates, incentives linked to stock price directly reduce managers' gains from breaking collusive agreements.

When stock-based incentives are deferred, the first pro-collusive effect is reinforced by the fact that the already limited beneficial effect on the stock price of short-run profits from a unilateral breach of a collusive agreement may be completely gone at the time when the manager receives the bonus. Then, the manager is left with no incentive whatsoever to break an agreement, which further stabilizes collusion.