Predatory Governance

Dalida Kadyrzhanova[1]

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[1]Department of Economics, Columbia University, New York, NY 10027. Phone/Fax: (212) 6621185. Email: drk19@columbia.edu. Web page: http://www.columbia.edu/~drk19. Richard Ericson and Michael Riordan provided much needed guidance and encouragement from the early stages of the project. I thank Atila Abdilkadiroglu, Kyle Bagwell, Dirk Bergemann, Anna Bordon, Prajit Dutta, Antonio Falato, Eslyn Jean-Baptiste, Bernard Salanie, and seminar participants at Columbia University and University of Rome Tor Vergata for helpful comments. All remaining errors are mine.

Abstract

This paper argues that imperfect corporate control is a determinant of market structure. We integrate a widely accepted version of the separation of ownership and control – Jensen's (1986) 'empire-building' hypothesis – into a dynamic oligopoly model (e.g., Ericson and Pakes (1995), Maskin and Tirole (2000)). Our main observation is that, due to product market competition, shareholders face an endogenous opportunity cost of governance. We derive shareholders' optimal governance choices and show analytically that governance has a first-order effect on firms' dynamic incentives to invest in cost reduction and leads to 1) increasing dominance, in the sense that the leading firm is more likely to stay ahead, once ahead, and 2) predation, in the sense that the leading firm drives rivals from the market. Through numerical simulations we demonstrate that imperfect corporate control has a sizable adverse impact on market structure and consumer welfare. It results in low turnover, high concentration, persistently monopolized markets, and low industry-wide investment. As a consequence, consumer welfare is significantly - up to thirty percent - lower than in otherwise identical industries with full corporate control. These results suggest a role for public policy toward corporate governance as an effective pro-competitive tool.

1 Introduction

What are the determinants of corporate governance? Why do firms exhibit such wide variation in their corporate governance arrangements, with larger, more established firms having weaker shareholder rights, less transparency, and overly excessive CEO compensation than their smaller rivals? Why do firms sometimes change their governance arrangements, and why are these changes infrequent? Despite substantial progress in research on optimal governance, these questions have been largely unanswered. In this paper, we explore an approach to the design of optimal governance based on the product market cost of managerial oversight, whereby owners/shareholders adapt governance to the competitive position of the firm, i.e. to own and rivals' position within the industry. We argue that a focus on product market competition can rationalize the firm and industry determinants of optimal governance and account for a number of regularities, such as for example the positive correlation between firm size and various governance indicators, the observed heterogeneity of corporate governance characteristics within industries, and strong persistence of governance regimes, uncovered by the empirical literature on corporate governance and firm and industry performance (Gompers, Ishii and Metrick (2003), Aggarwal and Samwick (1999)).

Traditional corporate finance models have ignored the role of product market competition in firms' choice of optimal corporate governance structures, where by corporate governance we mean the basic problem that "arises whenever an outside investor wishes to exercise control differently from the manager in charge of the firm." (Becht, Bolton, and Roell (2002)). This is a non-trivial problem as the investor's ability to prescribe a particular action to the manager is often limited due to a variety of reasons: inferior information, cost of monitoring manager's actions, collective action problem among investors, etc. In this paper, we willingly refrain from postulating an exogenous cost of governance - investors/shareholders are able to fully enforce any action - and argue that imperfect product market competition can be the source of limitations on the ability of shareholders to control managers. Indeed, even though managerial over-production is clearly wasteful from the standpoint of strict-profit maximization, with imperfectly competitive product markets, stronger governance, or less over-production, weakens firms in the product market as it induces rivals to optimally expand their size and leads to a loss of market share. Hence, the central trade-off in our paper is one between a loss of efficiency under lax control and a loss of market share under greater monitoring. Optimal governance choice arises as the solution to this non-trivial trade-off that emerges from our product market cum governance equilibrium.

Model We integrate a widely accepted version of the separation of ownership and control – Jensen's (1986) 'empire-building' hypothesis – into a dynamic industry equilibrium model of homogeneous product, quantity-setting oligopoly (e.g., Ericson and Pakes (1995), Maskin and Tirole (2000)). Firms are heterogeneous and differ in their marginal costs of production.

Every period, given current marginal costs, incumbent firms compete in the product market. Firms' shareholders delegate product market decisions to empire-building managers who, in the spirit of Jensen (1986), expand firms beyond the profit-maximizing size. The scope for delegation arises from the fact that the manager has superior information about product market (demand) conditions. Shareholders cannot observe demand and, following Grossman and Hart (1986) and Hart and Moore (1990), do not have the ability to contract on managers' actions, i.e. their output choices. As a consequence, shareholders cannot use a standard mechanism to elicit the manager's private information and, hence, to induce strict profit-maximization. They can, however, monitor managers' product market decisions by hiring "auditors." Auditors have a technology to observe output as it is produced, seize the produced goods so they do not fall under the control of the empire-building manager, and then transfer the resources back to the shareholders. As our auditing/monitoring technology broadly represents a variety of internal control mechanisms (e.g., debt, a change of board membership or charter, board supervision and so on), we refer to it as governance technology and to the optimal choice of monitoring intensity as governance choice.

We willingly refrain from postulating an exogenous cost of governance and we think of imperfect product market competition as the source of limitations on the ability of shareholders to control managers. To formalize an endogenous product market cost of corporate control we model (imperfect) control and product market decisions as a two-stage game. In the first stage, given the probability distribution of demand, shareholders choose governance to maximize their expected profits. In the second stage, 'empire-building' managers observe the realization of demand and then choose output to maximize their objective. Governance decisions are rational in the sense that shareholders choose monitoring intensity to maximize expected profits and correctly anticipate the (second-stage) equilibrium of the product market game between managers. Importantly, the second-stage product market decisions of managers will depend both on own and rivals' governance. Thus, the central trade-off shareholders face in their governance choices stems from the fact that stronger governance, aimed at limiting managerial tendencies for over-production, comes at the cost of preventing managers from pursuing aggressive product market strategies.

At the end of the period, profits are distributed to shareholders who then make R&D decisions aimed at lowering marginal costs and, ceteris paribus, increasing firm's market share. Moreover, entry and exit decisions take place. Our focus is on characterizing the way imperfect corporate control changes the dynamic interaction between competitors through its impact on product market outcomes. Since market structure ultimately results from this dynamic interaction between competitors, the model allows us to trace the effects of imperfect corporate control on market structure and its evolution over time.

Results Our main finding is that in imperfectly competitive industries weak governance, or lack of efficient oversight, allows industry leaders to maintain their lead and secure monopoly rents by driving rivals from the market. Based on this finding, we argue that corporate control imperfections have adverse consequences for market structure and consumer welfare. In particular, we show that they lead to persistently monopolized markets, lower turnover, higher concentration, and significantly - up to thirty percent - lower consumer welfare than in otherwise identical industries with full corporate control. These results strongly support public policy measures directed toward improving corporate governance, such as the Sarbanes-Oxley Act. In addition, they provide a formal rationale for a simple output rule as an effective anti-trust measure to counter predatory governance.

More formally, our main finding results from the characterization of the unique and symmetric Markov Perfect equilibrium of an oligopolistic industry with imperfect corporate control. For sufficiently high discounting, we show analytically that if the technological features of the industry are such that in every period advancements lead to increases in market shares that are not "too large" then imperfect corporate control has a first-order impact on firms' dynamic incentives to get ahead. In particular, imperfect corporate control can be shown to lead to increasing dominance, i.e. to a tendency for the leader to stay ahead, in industries where, with no imperfections in corporate control, convergence would always obtain, in the sense that the laggard would tend to catch up.

Our analytic results, thus, demonstrate that imperfect corporate control encourages R&D effort on the side of the leader and discourages R&D effort on the side of the laggard.

The intuition behind these results lies in the nature of the endogenous product market cost of governance. As we show, shareholders of large firms face higher product market cost of governance, and, hence, optimally choose weaker governance. As a consequence, the managers of big firms face less restraint in their "empire-building" tendencies and pursue more aggressive output strategies, which in a strategic environment has the added benefit of eliciting a less aggressive response from the managers of rival firms. Thus, by pulling ahead, the leader gains a strategic advantage over its rivals in the form of a more aggressive manager who can marginalize rival managers, and effectively captures the market through the strategic effects of managerial boldness - "empire-building". In turn, such a market, naturally, becomes less attractive to firms that fall behind since, due to over-production by the leading firm's manager, the return to R&D effort falls as their market shares decline. Together, these two forces imply that governance drives a wedge between the leader's and the laggard's dynamic incentives to undertake R&D: while the leader has a greater incentive to work harder to keep the strategic advantage that comes with the lead and, possibly, widen the gap more, the laggard's R&D is discouraged. If, in addition, there is a possibility that the lagging firm exits, the leader has an incentive to both choose weak governance and increase its R&D expenditures heavily, which increases the probability of exit. In this sense, governance imperfections can be characterized as predatory in the sense that they lead to rival-weakening and exit-inducing behavior.

Finally, the key feature of the optimal governance structures in our model is that, due to the interaction on imperfect product markets, at every point of time they depend on the current performance of the firm and the characteristics of its rivals. This enables us to characterize optimal governance as a function of both firm level and market level variables, and generate such empirically documented regularities as for example the positive correlation between firm size and various governance indicators (Gompers, Ishii and Metrick (2003), Aggarwal and Samwick (1999)). Moreover, the model enables us to develop a number of novel empirically testable implications on the relationship between corporate governance and firm performance and helps shed light on the strategic determinants of the observed heterogeneity of corporate governance characteristics within industries (e.g. Gompers, Ishii, and Metrick (2003), Cremers and Nair (2004)). In particular, it implies that firm governance differs across industries and depends on industry-level variables such as market size and degree of competition and firm-level variables such as its position within the industry and its status as entrant, incumbent, or exiting firm.

Related literature While our study of the link between corporate governance and product market competition within an explicit industry equilibrium setting is, to the best of our knowledge, novel to either corporate finance or industrial organization, there are various important strands of these literatures related to our work. Schematically, in corporate finance our work is related to numerous recent contributions which have sought to identify, both theoretically and empirically, the determinants and real implications of corporate governance. In industrial organization, we build on recent developments of structural dynamic oligopoly models to study the evolution of market structure. We detail on the most closely related work in these literatures in turn.

In our model, managers have a preference for "empire-building," i.e. they prefer to run large firms and, consequently, want to expand production beyond strict profit maximization. This idea has a fairly long history (e.g., see Baumol (1959), Marris (1964), Williamson (1964)). It has been documented in a number of empirical studies, starting from Donaldson (1984) and Murphy (1985). Dow, Gorton, and Krishnamurthy (2004) show that it can account for a number of features of aggregate investment and asset returns, while Philippon (2003) argues it can help accounting for differences in firm investment behavior over the business cycle. In the context of our model 'empire-building' preferences can arise from either of two potentially distinct sources that have both received attention in the empirical corporate finance literature: first, as observed by Jensen (1986), managers care about revenues more than owners as higher revenues increase manager's power by increasing the resources under their control (Murphy (1985) and Donaldson (1984) provide seminal empirical evidence of this effect); second, managers care about costs more than owners do (see Bertrand and Mullainathan (2003) for recent evidence).

Our chosen specification of managerial objectives as having two components, profits and private benefits, is entirely standard in corporate finance since the seminal contribution of Jensen and Meckling (1976). In the context of our model it provides a stylized motivation for the separation of ownership and control in line with a recent literature which employs managerial 'biases' to derive endogenously optimal corporate governance arrangements (e.g., Burkart, Gromb and Panunzi (1997) and Gomes and Novaes (2004) derive the optimal degree of the separation of ownership and control; Dessein (2002) derives the optimal degree of delegation in organizations). Our model is closest to Burkart, Gromb and Panunzi (1997) in that shareholders' commitments to not monitor are valuable since they foster managerial initiative. The mechanism through which delegation fosters managerial initiative distinguishes our model from theirs as we emphasize the effect of shareholders' commitment on the strategic interaction in imperfect product markets.

It is worth emphasizing that the main mechanism driving our results is testable: governance is weaker for relatively established incumbent firms with larger market shares, since their shareholders find it optimal to give managers more slack. This mechanism is broadly consistent with the stylized fact of corporate governance and firm characteristics (e.g. Gompers, Ishii and Metrick (2003), Cremers and Nair (2004)) that firms with weaker shareholder right, i.e. weaker governance, tend to be large S&P 500 firms. In general, our model predicts that corporate governance affects firm (and indeed industry) performance and that a firm's position within an industry as proxied, for example, by its market share matters for the effect of its corporate governance on performance. While recent empirical corporate finance literature has explicitly tested and found support for the first prediction, the second has not been formally tested and we leave it as an obvious important task for future research.

Our work is also related to the corporate finance literature on the relationship between product market competition and particular features of corporate governance, such as, for example, managerial compensation. Aggarwal and Samwick (1999) and Kedia (2003) build on earlier theoretical contributions of Fershtman and Judd (1987) and Sklivas (1987) and document that some industry level variables, such as, for example, the Herfindahl index or whether firms compete in strategic complements or substitutes, are determinants of top management compensation. Scharfstein (1988), Schmidt (1997), and Raith (2003) study the link between product market competition and managerial incentives within models of monopolistic competition. The main question in this literature pertains to whether more intense product market competition improves incentives. We do not model an explicit incentive provision problem. However, we are also interested in understanding the effect of product market competition on shareholders' monitoring decisions and, ultimately, on the costs of managerial agency. Our dynamic industry equilibrium setting allows for strategic interaction among heterogeneous oligopolists, hence enriching the set of determinants of cross-sectional differences in firms' governance. It also contributes to this literature by bringing the theoretical predictions of this class of models closer to the data. While, in fact, attempts to empirically test the predictions of these models have been hampered by the notorious difficulty to find empirical proxies for the intensity of competition, our model links governance to a richer set of observable firm characteristics in the product market, such as, for example, position within the industry and status as entrant, incumbent, or exiting firm.

Our main argument that imperfect corporate control changes the dynamic interaction between competitors through its impact on product market outcomes builds on recent theoretical advances in industrial organization. In particular, we introduce optimal corporate governance choices into a dynamic oligopoly setting (Ericson and Pakes (1995), Pakes and McGuire (1994, 2001), Doraszelski and Satterthwaite (2003)). The existing literature (see Besanko and Doraszelski (2004) for a recent example) has pursued a computational approach to the Markov-perfect Nash industry equilibrium (see Maskin and Tirole (1988, 2000)). Our contribution is to offer within this setting, to our knowledge for the first time, an explicit analytic characterization of equilibrium for the case of high discounting.

Our analytic characterization allows us to uncover a set of effects leading to persistent industry leadership which is richer than in the previous literature on increasing dominance (Vickers (1986), Cabral and Riordan (1993), Budd, Harris and Vickers (1996), Bagwell, Ramey and Spulber (1997), Athey and Schmutzler (2001)). Our analytic results are obtained employing asymptotic expansions in the interest rate, a method which is closely related to Budd, Harris and Vickers (1993) who, however, limit their analysis to one-dimensional product market rivalry, where firm profits are determined by the difference between its current state and the state of its rival. By contrast, we are able to uncover a novel source of increasing dominance by explicitly modelling product market rivalry as two-dimensional. Our sufficient conditions for increasing dominance are a result of independent interest as they extend the previous literature to the case of heterogeneous firms.

Finally, ours is a theory of predation based on imperfections in corporate control. While we are not the first to draw from corporate finance to understand predation (see Bolton and Scharfstein (1990) for a theory of predation based on financing problems), our appeal to corporate governance as a source of predation is novel. Admittedly, the very notion of predation remains contentious and has been object of intense debate (see Bolton, Brodley, and Riordan (2000) for a careful discussion of the strategic approach to predation and Bolton, Brodley, and Riordan (2001) for an account of the criticisms). We make several distinct contributions to the predation literature. First, employing a structural model allows us to address the essentially empirical question of whether for realistic parameters the welfare costs of predation offset the welfare benefits of the more intense rivalry it brings about. Second, in contrast to existing models of predation, we allow for both endogenous entry and exit and we show that governance imperfections have a lasting impact on market structure exactly since they give rise to both entry deterrence and exit inducement. A further important benefit of allowing for endogenous entry and exit is that even though predation takes place, it is always rational for the prey to enter. Moreover, asymmetries between competitors arise endogenously in our model as a result of the dynamic interaction in the product market and are not postulated at the outset as in much existing literature of predation. This, together with our assumption of realistic uncertainty, allows us to avoid one more controversial aspect of existing predation models, i.e. the counterfactual implication that once successful predation takes place monopoly rents are earned forever after. Lastly, it is often contended that it may be difficult to distinguish harmful predation from beneficial competition. Managerial 'empire-building' preferences are an appealing source of predation from the perspective of antitrust enforcement since they leave an unmistakable 'mark' of predation in the product market and can be effectively countered with the introduction of a simple output ceiling rule.

Outline Section 2 presents our dynamic model of an oligopolistic industry with imperfect corporate control and defines a unique and symmetric Markov perfect equilibrium (MPE). Section 3 characterizes the equilibrium in the product market and its implications for optimal governance choices. Section 4 characterizes the MPE analytically for the case of high discounting and shows that governance imperfections give rise to increasing dominance and predation. Section 5 contains a numerical characterization of the MPE and shows that increasing dominance and predation obtain for general discount rates. Through numerical simulations it is argued that imperfect corporate control has a sizable adverse effect on market structure and consumer welfare. Finally, the implications of these results for antitrust policy are considered. The last section concludes and discusses directions for future work. All proofs and detailed derivations are contained in the appendix.

2 The Model

This section integrates a widely accepted version of the separation of ownership and control – Jensen's (1986) 'empire-building' hypothesis – into a dynamic industry equilibrium model with imperfect competition. Time is discrete and time horizon is infinite. There are two groups of firms, incumbents and potential entrants. Incumbent firms are heterogeneous and differ in their marginal costs of production. Every period, firms make entry, exit, and R&D effort decisions. Moreover, firm shareholders delegate product market decisions to empire-building managers who, in the spirit of Jensen (1986), expand firms beyond the profit-maximizing size. Shareholders have an auditing/monitoring technology available to discipline managers, but this involves a cost that arises endogenously from the product market.

2.1 Timing and physical states

Every period t there are $n_t \leq N$ heterogeneous firms that differ in their marginal costs of production, $c(\omega_{it})$. Each of the $i = 1, ..., N$ firms' marginal cost is indexed by an integer $\omega_{it} \in \mathcal{Z}^+$, a firm's individual "state". Higher states correspond to lower costs, i.e. $c(\omega_{it} + 1) < c(\omega_{it})$. We follow standard practice (e.g. Ericson and Pakes (1995), Budd, Harris and Vickers (1993)) and parametrize the cost of each firm as an exponential function of its individual "state", i.e. $c(\omega_{it}) = e^{-\omega_{it}} + \gamma$. The distribution of incumbent firms' marginal costs, $(\omega_{1t}, \omega_{2t}, ..., \omega_{n_t t})$ $\in \Omega^{n_t}$, summarizes the state of the industry at each point of time. The model's primitives as well as firm's own state, ω_{it}, and the state of its rivals, $\omega_{-it} = (\omega_{1t}, ..., \omega_{i-1t}, \omega_{i+1t}, ..., \omega_{n_t t})$, $\forall i = 1, ..., n_t$ are common knowledge.

The timing is as follows. At the beginning of each period current marginal costs, $c(\omega_{it})$, are observed and incumbent firms decide on exit and R&D expenditures. Potential entrant observe setup cost and decide whether to enter. After entry, exit, and R&D decisions, corporate control decisions are made and product market competition takes place. To formalize an endogenous product market cost of corporate control we model (imperfect) control and product market decisions as a two-stage game: in the first stage, shareholders choose the optimal monitoring intensity; in the second stage, 'empire-building' managers make output choices. Corporate control decisions are rational in the sense that shareholders choose monitoring intensity by maximizing expected profits and correctly anticipate the (second-stage) product market equilibrium. At the end of the period, exit, entry, and R&D take place. The outcome of current R&D is realized at the beginning of the next period, when firms observe their marginal costs $c(\omega_{it+1})$.

2.2 Product market competition and governance problem

Every period, firms compete in a homogeneous product, quantity-setting oligopoly. Product market decisions are delegated to managers since there is demand uncertainty and managers can directly observe realized demand while shareholders cannot. This formalizes the idea that managers have a comparative advantage over shareholders as they possess more hands-on knowledge of market conditions and, consequently, are better able to make informed product market decisions. In line with this assumption, whenever we specialize the model to the case of linear demand, $P = D - bQ$, we allow for uncertainty in the slope of the demand curve, b, where we do not assume any particular distribution of b, and only require that the support of the distribution of b is positive and its mean is normalized to one, $E(b) = 1$. This assumption is convenient as it implies that although managerial decisions and payoffs are indexed by demand uncertainty we can safely study them for a given realization of b (and scale for others), thus allowing us to omit indexing by demand uncertainty and ease notation. Moreover, it is without loss of generality as the alternative assumption of uncertainty over the demand intercept delivers qualitatively equivalent results.

We use a widely accepted theory of managerial preferences, Jensen's (1986) 'empire-building' hypothesis, to motivate in a stylized yet realistic way the separation of ownership and control, which in the present context arises due to the fundamental discrepancy between the objectives of empire-building managers and profit-maximizing shareholders. In fact, while shareholders maximize profits, managers in our model have a preference for "empire-building," i.e. they prefer to run large firms and, consequently, want to expand production beyond strict profit maximization. The idea that managers are "empire-builders" has a fairly long history (e.g., see Baumol (1959), Marris (1964), Williamson (1964)). It has been documented in a number of empirical studies, starting from Donaldson (1984) and Murphy (1985).

In particular, managerial preferences $M(q_{it}, q_{-it}; \omega_{it})$ are observable and given by

$$M(q_{it}, q_{-it}; \omega_{it}) = \pi(q_{it}, q_{-it}; \omega_{it}) + B(q_{it}, q_{-it}; \omega_{it})$$

where $\pi(q_{it}, q_{-it}; \omega_{it}) = P(q_{it}, q_{-it}) q_{it} - c(\omega_{it}) q_{it}$ represents firm profits and $B(q_{it}, q_{-it}; \omega_{it}) > 0$ summarizes manager's private benefits of control. Our chosen specification of managerial objectives as having two components, profits and private benefits, is entirely standard in corporate finance since the seminal contribution of Jensen and Meckling (1976).

To characterize 'empire-building' we assume that $\frac{\partial B(q_{it}, q_{-it}; \omega_{it})}{\partial q_{it}} > 0$. The appendix shows that the second order conditions of the optimal choice of output imply that this assumption is sufficient to obtain over-production, i.e. for the manager to expand the firm beyond its strict-profit maximizing size. To build intuition on $B(\cdot)$, it is useful to observe that in the context of our model 'empire-building' preferences can arise from two potentially distinct sources, that have both received attention in the corporate finance literature:

1. Managers care about revenues more than shareholders do, i.e. $B(\cdot) = \lambda P(q_{it}, q_{-it}) q_{it}$, with $\lambda > 0$; in this

case their objective 'over-weights' revenues with respect to strict-profit maximization, i.e. $M(q_{it}, q_{-it}; \omega_{it}) = (1+\lambda) P(q_{it}, q_{-it}) q_{it} - c(\omega_{it}) q_{it}$. Jensen (1986) observed that higher revenues increase manager's power by increasing the resources under their control. Murphy (1985) documents that changes in managerial compensation are positively related to changes in revenues. Donaldson (1984) in his study of 12 large Fortune 500 firms concludes the managers of these firms were not driven by the maximization of the value of the firm, but rather by the maximization of corporate wealth, defined as the aggregate purchasing power available to management (p. 3). Finally, higher revenues increase the extent to which managers can extract perks, i.e. non-pecuniary benefits like "fancy offices, private jets, the easy life, etc... that are attractive to management but are of no interest to shareholders" (Hart (2001)).

2. Managers care about costs more than shareholders do, i.e. $B(\cdot) = \lambda c(\omega_{it}) q_{it}$, with $\lambda > 0$; in this case their objective 'under-weights' costs with respect to strict-profit maximization, i.e. $M(q_{it}, q_{-it}; \omega_{it}) = P(q_{it}, q_{-it}) q_{it} - (1-\lambda) c(\omega_{it}) q_{it}$. Bertrand and Mullainathan (2003) document that managers appear to care more about workers, especially white-collar workers, than shareholders do. This care for workers and suppliers in general may result from a desire to avoid conflict with unions, ease interactions, or have higher-quality employees and suppliers. However, managers are likely to care about costs also if they derive private benefits from dealing with suppliers: recent scandals revealed kick back practices between managers and suppliers were widespread during the 90's to the point of being characterized in the popular press as a 'kick back culture' (e.g. Business Week, February 2003). For example, Wall Street firms allocated coveted IPO shares to the private accounts of CEOs such as Ford Motor Co.'s William Clay Ford and WorldCom Inc.'s Bernard J. Ebbers, allegedly to win future banking business. On Dec. 20, regulators negotiated a \$1.4 billion settlement with 10 investment banks that, among other requirements, barred such practices.

The Appendix shows that the congruence parameter $\lambda > 0$ can be conveniently rescaled so that both formulations imply the same choice of output on the side of the manager. Consequently, our framework allows us to characterize λ as a measure of the 'empire-building' tendencies of the manager, i.e. of his preference for over-production, without having to commit to any particular source of such behavior. Moreover, this parametric formulation of congruence between shareholders' and managers' preferences is in line with the recent optimal delegation literature that employs managerial 'biases' to study the optimal degree of delegation in organizations (see, for example, Dessein (2002)) and the optimal separation of ownership and control (see, for example, Burkart, Gromb and Panunzi (1997), Gomes and Novaes (2004)).

How can profit maximizing shareholders, who do not observe demand, make sure managers disgorge the cash rather than wasting it in over-production? Following Grossman and Hart (1986) and Hart and Moore (1990), we assume that shareholders do not have the ability to contract on managers' actions, i.e. their output choices. As a consequence, shareholders cannot use a standard mechanism to elicit the manager's private information and, hence, to induce strict profit-maximization. They have, however, one lever to control managers' output decisions in the product market. In particular, an auditing/monitoring technology is available to them: every period they optimally hire the profit-maximizing number of "auditors," a_{it}, to monitor the firm. Auditors have a technology to observe output as it is produced, seize the produced goods so they do not fall under the control of the empire-building manager, and then transfer the resources back to shareholders. There are A auditors available and shareholders can seize total firm output only by hiring all auditors available. Consequently, $\frac{a_{it}}{A} \equiv \alpha_{it}$ of available auditors can seize $\alpha_{it} q_{it}$ units of output and when $\alpha_{it} = 1$ (or, equivalently, $a_{it} = A$) shareholders enforce full profit maximization. As our auditing/monitoring technology broadly represents a variety of internal control mechanisms (e.g., debt, a change of board membership or charter, board supervision and so on), we refer to it as governance technology and to the optimal choice of monitoring intensity, α_{it}, as governance choice.

Governance choices, α_{it}, measure the extent to which shareholders induce strict-profit maximizing behavior on the side of the manager. A straightforward interpretation of this governance technology is that shareholders, say through the board, can either rubber-stamp the production plan proposed by the manager, or they can scrutinize it. Scrutinizing allows to cut on wasteful over-production and to make sure that the project is implemented on the right scale. We willingly refrain from postulating an exogenous cost of governance and we think of imperfect product market competition as the source of limitations on the ability of shareholders to control managers: in our model governance is costly since it makes firms 'softer' in the product market.

To formalize an endogenous product market cost of governance we model (imperfect) control and product market decisions as a two-stage game. In the first stage, given the probability distribution of demand, shareholders simultaneously choose governance $(\alpha_{1t}, ..., \alpha_{n_t t})$ to maximize expected profits. In the second stage, given governance, 'empire-building' managers observe the realization of the demand uncertainty and then choose output to maximize $M(q_{it}, q_{-it}; \omega_{it}, \alpha_{it}) = \pi(q_{it}, q_{-it}; \omega_{it}) + B((1-\alpha_{it}) q_{it}, q_{-it}; \omega_{it})$. Corporate control decisions correctly anticipate the (second-stage) product market equilibrium. We follow standard practice (e.g. Fudenberg and Tirole (1998)) and solve for the unique symmetric subgame perfect equilibrium of this two-stage game by backward induction to obtain $q^*(\omega_{it}, \omega_{-it})$, $P^*(\omega_t)$, and $\pi^*(\omega_{it}, \omega_{-it})$.

2.3 Entry, exit, and R&D

Given profits that result from the product market *cum* governance game, $\pi^*(\omega_{it}, \omega_{-it})$, the shareholders of an incumbent firm have two choices - whether to exit or remain active, and if the firm remains active, how much R&D to undertake. Spending an amount x_t on R&D increases the probability distribution of improvements in ω_i. Consistent with well documented empirical properties (see, for example, Hall et al. (1986) and Lach and Schankerman (1988), and Cohen (1995) for a survey), R&D has an uncertain outcome, i.e. although higher R&D increases the likelihood of success, it does not guarantee cost reduction. If a string of unsuccessful outcomes occurs, shareholders may find it optimal to liquidate the project. If an incumbent decides to exit it gets a sell-off value of ϕ_i dollars, exits in the next period and never reappears again. We assume that the scrap value is a constant ϕ, same across all firms. We let $\chi_i \in \{0, 1\}$ indicate exit ($\chi_i = 0$) or continuation ($\chi_i = 1$).

Thus if we let $(1+r)^{-1}$ be the discount factor common to all firms, and $p\left(\omega_i', \omega_{-i}' | x, \omega_i, \omega_{-i}\right)$ provide the firm shareholder's perception of the joint probability that own firm's efficiency in the next period will be ω_i' and the rivals' will be ω_{-i}' conditional on $(x, \omega_i, \omega_{-i})$, firm shareholders maximize the discounted net present value of dividends. Hence, they choose exit and R&D spending according to the following Bellman equation

$$\begin{aligned} V\left(\omega_i, \omega_{-i}\right) &= \max\left\{\phi, \sup_{d,x\geq 0}\left\{d\left(\omega_i, \omega_{-i}\right) + \frac{1}{1+r}E_{(\omega_i,\omega_{-i})}V\left(\omega_i', \omega_{-i}'\right)\right\}\right\} \\ d\left(\omega_i, \omega_{-i}\right) &= \pi\left(\omega_i, \omega_{-i}\right) - x \end{aligned} \tag{1}$$

where $E_{(\omega_i,\omega_{-i})}V\left(\omega_i', \omega_{-i}'\right) = \sum_{\left(\omega_i', \omega_{-i}'\right)\in\Omega} V\left(\omega_i', \omega_{-i}'\right) p\left(\omega_i', \omega_{-i}' | x, \omega_i, \omega_{-i}\right)$. If a firm is not liquidated, at an interior solution, standard perturbation arguments imply that shareholders choose R&D spending, $x^*\left(\omega_i, \omega_{-i}\right)$, as follows:

$$\frac{\partial E_{(\omega_i,\omega_{-i})}V\left(\omega_i', \omega_{-i}'\right)}{\partial x^*} = 1 + r \tag{2}$$

The intuition for the optimality condition for R&D is entirely standard: shareholders increase R&D until at the margin its value equals its cost. It is straightforward to observe that, since we assume $p\left(\omega_i', \omega_{-i}' | x, \omega_i, \omega_{-i}\right)$ is a concave function of x, an interior solution obtains as long as $\frac{\partial EV\left(\omega_i', \omega_{-i}'\right)}{\partial x}|_{x=0} > 1 + r$.

At every period, if $n_t < N$, there are potential entrants who might decide to enter the industry. To enter they must pay a sunk cost of x^e. An entrant appears in the following period as an incumbent at an $\omega_i' = \omega^e - \nu_i'$, where ω^e is given. For simplicity most models assume there is at most one entrant in every period, and indicate whether entry occurs by the indicator function $\chi^e \in \{0, 1\}$, $\chi^e = 1$ indicating entry.

To complete this section we are left with a description of the probability function. States evolve according to the transition rule

$$\omega_i' = \omega_i + \nu_i - \xi \tag{3}$$

where ν_i is firm-specific and depends on R&D level, $P\left(\nu_i | \omega_i, \omega_{-i}, x\right) = P\left(\nu_i | x\right)$, and ξ is common for all the firms, exogenous and iid over time, $P\left(\xi | \omega_i, \omega_{-i}, x\right) = P\left(\xi\right)$. It represents the value of the outside alternative.

$P\left(\nu_i | x\right)$ is assumed to be stochastically increasing in x (i.e. $P\left(\cdot | x_1\right)$ is better, in the first order stochastic dominance sense, than $P\left(\cdot | x_2\right)$ whenever $x_1 > x_2$). Both ν and ξ are non negative, integer-valued, random variables; $\nu = 0$ with probability one if $x = 0$ (a firm cannot advance without some R&D), and $P\left(0 | x\right) = 0$ for all finite x.

Notice that $p\left(\omega_i', \omega_{-i}' | \omega_i, \omega_{-i}, x\right) = \mathbf{P}(\omega_{-i}' | \omega_{-i}) \cdot P\left(\omega_i' | \omega_i, x\right)$. Thus, although shareholders know that $P\left(\omega_i' | \omega_i, x\right) = \sum_\xi P\left(\xi\right) P\left(\nu_i = \omega_i' - \omega_i + \xi | x\right)$, for $\mathbf{P}\left(\omega_{-i}' | \omega_{-i}\right)$ they need to know the R&D and exit decision rules of the other shareholders. Therefore, $\mathbf{P}\left(\omega_{-i}' | \omega_{-i}\right)$ depends on the equilibrium of the model.

2.4 Equilibrium

Each firm (i.e., its shareholders) makes entry, exit, and R&D decisions to maximize expected discounted profits. Our solution concept for the industry with imperfect corporate control is symmetric Markov perfect equilibrium (MPE). This is a subgame perfect equilibrium, where each firm's strategy depends only on the "payoff-relevant" (Maskin and Tirole (1988, 1995)) state of the game, $\omega = (\omega_1, \omega_2, ..., \omega_{n_t})$. A strategy for an incumbent firm i is a mapping $\sigma(\omega_i, \omega_{-i})$ from the state space $(\omega_i,\ \omega_{-i})$ into the decision space (x, χ) that gives the firm's R&D and exit decision for every possible state, while a strategy for an entrant is a $\sigma^E(\omega_i^E, \omega_{-i})$ from the state space (ω_i^E, ω_{-i}) into the decision space (ξ) that gives the entry decision for every possible state,. Suppose that a firm believes that all other firms behave according to the decision rule $\sigma(\cdot, \cdot)$. Given $\sigma(\cdot, \cdot)$ and the stochastic processes of $\{\nu'\}$ and $\{\xi'\}$, a firm can obtain the transition probability for the market structure $\{\omega_{-i}, \omega_{-i}\}$, $P(\omega_i', \omega_{-i}' | \omega_i, \omega_{-i}; \sigma)$, and solve its dynamic decision problem. This solution provides an optimal decision rule for R&D expenditures (dividends) and exit: $(x, \chi) = \psi(\omega_i, \omega_{-i}|\sigma)$. This optimal decision rule is conditional on the belief that other firms follow σ. In this sense, $\psi(\cdot|\sigma)$ is a best-response mapping in the space of strategy functions.

Markov Perfect Nash Equilibrium is defined by a strategy function $\sigma^*(\omega_i, \omega_{-i})$ such that, for every (ω_i, ω_{-i})

$$\sigma^*(\omega_i, \omega_{-i}) = \psi(\omega_i, \omega_{-i}|\sigma^*)$$

Note that the MPE σ^*gives the equilibrium transition probability for the market structure: $\mathbf{P}(\omega_i',\ \omega_{-i}'\ |\omega_i,\ \omega_{-i};\ \boldsymbol{\sigma}^*)$.

The appendix shows our model satisfies the boundedness, continuity, and uniqueness requirements in Proposition 4 in Doraszelski and Satterthwaite (2003), which allows us to establish the following:

Proposition 1 *A unique rational expectations MPE, $\sigma^*(\omega_i, \omega_{-i})$, exists.*

3 Optimal Governance

In this section we characterize the equilibrium in the product market and its implications for optimal governance choices. In the second stage subgame, given governance choices $(\alpha_{1t}, ..., \alpha_{n_t t})$, the Cournot-Nash equilibrium in the managers' output strategies is characterized by the set of first-order conditions $\frac{\partial \pi(q_{it}, q_{-it}; \omega_{it})}{\partial q_{it}} + \frac{\partial B((1-\alpha_{it})q_{it}, q_{-it}; \omega_{it})}{\partial q_{it}} = 0$, $\forall i = 1, ..., n_t$. These conditions define managers' output reaction functions in implicit form. The implied solution gives prices, $P_t^M = P\left(\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-it}\right)$, and quantities, $q_{it}^M = q\left(\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-it}\right)$, as a function of the industry distribution of costs, $\left(\omega_{it}, \omega_{-it}\right)$, and given shareholders' governance decisions $(\alpha_{it}, \alpha_{-it})$. Better governance, i.e higher monitoring intensity, shifts manager's reaction function inward and decreases output (and market share), holding rivals' governance constant. In particular, the Appendix shows that, for the case when $n_t = 2$, by totally differentiating the first-order conditions with respect to governance choice the following obtains: $\frac{\partial q_i}{\partial \alpha_i} = A \frac{\partial B_i}{\partial q_i} \frac{\partial^2 M_{-i}}{\partial q_{-i}^2}$, where A is a function of own and cross effects of output on marginal profits and is strictly positive for strictly concave managerial objective functions. Since managers are empire-builders, $\frac{\partial B_i}{\partial q_i} > 0$, and strict concavity of the managerial objective function implies that $\frac{\partial^2 M_{-i}}{\partial q_{-i}^2} < 0$. Hence, $\frac{\partial q_i}{\partial \alpha_i} < 0$. Similarly, $\frac{\partial q_{-i}}{\partial \alpha_i} = -A \frac{\partial B_i}{\partial q_i} \frac{\partial^2 M_{-i}}{\partial q_{-i} \partial q_i}$. As the two firms compete in quantities their strategies are strategic substitutes in the sense that increasing the output of firm $-i$ decreases the total and marginal revenue of firm i. This implies that $\frac{\partial^2 M_{-i}}{\partial q_{-i} \partial q_i} < 0$, and, hence, $\frac{\partial q_{-i}}{\partial \alpha_i} > 0$. In the remainder of this section we show that a product market cost of corporate control arises endogenously in the context of our model due to these 'real' consequences of governance choices.

In the first stage subgame, shareholders choose governance, $\alpha_{it} = \alpha^* (\omega_{it}, \omega_{-it})$, to maximize profits $\pi_i (\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-}$ given manager output choices $(q (\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-it}), ..., q (\omega_{n_t t}, \omega_{-n_t t}, \alpha_{n_t t}, \alpha_{-n_t t}))$. The Nash equilibrium in governance strategies is characterized by the set of first-order conditions $\frac{\partial \pi_i(\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-it})}{\partial \alpha_{it}} = 0$, $\forall i = 1, ..., n_t$, or, equivalently,

$$\frac{\partial B_i}{\partial q_i} \frac{\partial q_i}{\partial \alpha_i} = \frac{\partial \pi_i}{\partial q_{-i}} \frac{\partial q_{-i}}{\partial \alpha_i} \tag{4}$$

Due to imperfect product market competition corporate control is costly and, as a consequence, at the margin optimal governance choices have to trade-off the benefit of monitoring managers against this cost. The left hand side of equation (4) represents the marginal benefit of governance for shareholders: stronger governance, i.e. higher monitoring intensity, α_i, allows to cut on wasteful over-production as $\frac{\partial q_i}{\partial \alpha_i} < 0$. This benefit is higher the more pronounced managerial empire-building tendencies ($\frac{\partial B_i}{\partial q_i} > 0$) are. Efficiency gains, however, are traded-off against the (endogenous) product market cost of governance, $\frac{\partial \pi_i}{\partial q_{-i}} \frac{\partial q_{-i}}{\partial \alpha_i}$, as stronger governance weakens firms in the product market. In fact, cutting on over-production, $\frac{\partial q_i}{\partial \alpha_i} < 0$, translates into an inward shift of the firm's output best-response curve and a consequent 'toughening' of its rival, $\frac{\partial q_{-i}}{\partial q_i} < 0$, i.e. a movement along its output best-response curve. As a result, $\frac{\partial q_{-i}}{\partial \alpha_i} = \frac{\partial q_{-i}}{\partial q_i} \frac{\partial q_i}{\partial \alpha_i} > 0$. Importantly, this is more costly the larger is the reduction in profit caused by the 'toughening' of the rival, $\frac{\partial \pi_i}{\partial q_{-i}} < 0$.

Our main result of this section, which we prove in the Appendix, is that, due to the strategic cost of corporate control, shareholders in equilibrium choose not to exercise governance to its full extent:

Proposition 2 *With oligopoly,* $\alpha^* (\omega_{it}, \omega_{-it}) < 1$, $\forall i, -i \in N, \forall t$. *With monopoly and perfect competition,* $\alpha^* (\omega_{it}) = 1$, $\forall i, \in N, \forall t$.

In words, even though we have not postulated any exogenous cost of governance and managerial over-production is clearly wasteful from the standpoint of strict-profit maximization, a non-trivial trade-off emerges from our product market *cum* governance equilibrium. As the linear example below illustrates, corporate control imperfections are tied to product market imperfections: shareholders face an endogenous opportunity cost of governance that arises from the interactions in imperfectly competitive product markets. Consequently, shareholders in general choose weak governance, i.e. never fully monitor managerial output choices.

The resulting product market equilibrium is given by $q^*(\omega_{it}, \omega_{-it}) = q^M(\omega_{it}, \omega_{-it}, \alpha^*_{it}, \alpha^*_{-it})$, $P^*(\omega_t) = P^M(\omega_t, \alpha^*_{it}, \alpha^*_{-it})$, and $\pi^*(\omega_{it}, \omega_{-it}) = \pi^M(\omega_{it}, \omega_{-it}, \alpha^*_{it}, \alpha^*_{-it})$. Given market structure, the product market equilibrium with imperfect corporate control, i.e. $\alpha_i < 1$, $i = 1, ..., n_t$, is characterized by lower prices, higher total output, and lower profits than the corresponding Cournot equilibrium with full monitoring.

3.0.1 Linear Cournot case

To illustrate the endogenous product market cost of governance, we derive manager's output and shareholder's governance decisions for the case of linear Cournot duopoly with inverse demand $P(Q) = D - bQ$, where $Q = q_1 + q_2$, $b = b_H$ with probability p and $b = b_L$ with probability $(1-p)$, and $E(b) = 1$. For the sake of exposition we parametrize $B(\cdot) = \lambda c(\omega_i) q_i$, $i = 1, 2$, set $\lambda = 1$ and omit time subscripts. The Appendix contains details of the derivations.

Manager's best-response output satisfies

$$q_i(q_{-i}; \omega_i, \alpha_i, b) = \frac{D - q_{-i} - \alpha_i c(\omega_i)}{2b}$$

Notice that only with perfect monitoring, i.e. $\alpha_i = 1$, managers' output strategy reduces to Cournot best-response and that, given q_{-i}, imperfect corporate control, $\alpha_i < 1$, implies $q_i > q_i^C$. It is straightforward to observe that $\frac{\partial q_i}{\partial \alpha_i} < 0$, $\frac{\partial q_{-i}}{\partial \alpha_i} > 0$, i.e. a firm shareholder's choice of strong governance, i.e. higher monitoring intensity, is costly as it induces rivals to optimally expand their size. Equilibrium output, price and profits are given by $q^*(\omega_{it}, \omega_{-it}, \alpha_{it}, \alpha_{-it}) = \frac{D + \alpha_{-i} c(\omega_{-i}) - 2\alpha_i c(\omega_i)}{3b}$, $P^*(\omega_t, \alpha_{it}, \alpha_{-it}) = \frac{D + \alpha_i c(\omega_i) + \alpha_{-i} c(\omega_{-i})}{3}$ and $\pi^*(\omega_t, \alpha_{it}, \alpha_{-it}) = \frac{(D + \alpha_i c(\omega_i) + \alpha_{-i} c(\omega_{-i}) - 3c(\omega_i))(D + \alpha_{-i} c(\omega_{-i}) - 2\alpha_i c(\omega_i))}{9b}$.

Shareholder's best-response governance satisfies

$$\alpha_i(\alpha_{-i}; \omega_i, \omega_{-i}) = 1 - \frac{D + \alpha_{-i} c(\omega_{-i}) - 2c(\omega_i)}{4c(\omega_i)}$$

and equilibrium governance choices are given by

$$\alpha^*(\omega_i, \omega_{-i}) = 1 - \frac{D + 2c(\omega_{-i}) - 3c(\omega_i)}{5c(\omega_i)}$$

It is straightforward to observe that in general $\alpha_i < 1$. Moreover, optimal choice of governance, α^*, does not depend on demand uncertainty.

3.1 Firm and industry level determinants of optimal governance

At every point of time the current state of competition in the industry is summarized by (ω_i, ω_{-i}) and whenever $\omega_i \geq \omega_{-i}$, firm i is the current industry leader and firm $-i$ is the laggard. The evolution of the state of the industry is driven by firms' R&D, given the stochastic transition rule for individual firm states (3). For example, if firm i spends more on R&D than $-i$, then i is more likely to advance than its rival. In the next section we will characterize analytically the MPE of the stochastic R&D game and show that governance affects the dynamic incentives to undertake R&D of leader and laggard in a differential way through its impact on firm profits in the product market. Here we show that imperfections in corporate control that stem from imperfect product market competition lead to systematic differences in the optimal governance choices of leader and laggard. In particular, any asymmetry in industry structure, i.e. difference between the state of the leader and the state of the laggard, translates into asymmetric governance choices across firms. We view these results as being of independent interest as they shed light on the strategic determinants of the observed heterogeneity of corporate governance characteristics within industries (e.g. Gompers, Ishii, and Metrick (2003)). They also prove helpful in building intuition on the mechanism behind the main result of next section, i.e. imperfect corporate control encourages R&D spending on the side of the leader and discourages R&D spending on the side of the laggard.

To this end, consider the first order conditions of optimality of shareholder governance choices (4). In the linear Cournot case with $\lambda = 1$, they reduce to

$$2\left(1 - \alpha^*\left(\omega_i, \omega_{-i}\right)\right) c\left(\omega_i\right) = q^*\left(\omega_i, \omega_{-i}\right)$$

The left hand side term represents the marginal benefit of governance for shareholders: stronger governance, i.e. higher monitoring intensity, α_i, allows to cut on wasteful over-production. At the margin, expenditure on an extra unit of output is measured by the unit cost of production, hence, $c\left(\omega_i\right)$ measures the marginal benefit of governance. Efficiency gains, however, are traded-off against the (endogenous) product market cost of governance, here $q^*\left(\omega_i, \omega_{-i}\right)$, as stronger governance weakens firms in the product market. In fact, cutting on over-production translates into an inward shift of the firm's output best-response curve and a consequent 'toughening' of its rival. As a result, at the margin stronger governance implies that profit are reduced by $q^*\left(\omega_i, \omega_{-i}\right)$.

At least two features that transpire from this characterization of optimal governance choices are worth emphasizing: first, while the benefit of governance is a direct implication of our assumption of 'empire-building' managers, the cost arises fully endogenously from the interaction in product markets; second, while the benefit of governance is a direct function only of the own state, ω_i, the cost depends also on the state of the rival, ω_{-i}. In this sense, the interaction on imperfect product markets is key to deliver the dependence of equilibrium governance choices on industry structure.

The following proposition summarizes the key properties of optimal governance and its dependence on market structure:

Proposition 3 (Optimal Governance) $\forall\left(\omega_i, \omega_{-i}\right) \in \Omega^2$, *optimal governance choices,* $\alpha^*\left(\cdot\right)$, *satisfy:*

1. *if* $\omega_i > \tilde{\omega}_i$, *then* $\alpha^*\left(\omega_i, \omega_{-i}\right) - \alpha^*\left(\tilde{\omega}_i, \omega_{-i}\right) < 0$,

2. if $\omega_j < \tilde{\omega}_j$*, then* $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_i, \tilde{\omega}_{-i}) < 0$*;*

3. if $\omega_i > \omega_{-i}$*, then*

(a) $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) < 0$*;*

(b) $\alpha^*(\omega_i + 1, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i + 1) << \alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i)$*,*

(c) $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) << \alpha^*(\omega_i, \omega_{-i} + 1) - \alpha^*(\omega_{-i} + 1, \omega_i)$*.*

Proof. *See Appendix.* ■

We discuss these properties in turn and, in the next section, examine their competitive effects. Properties 1 and 2 state that it is optimal for firms with larger market share to choose weaker governance. This result stems from two sources. First, large market shares can arise either when own state, ω_i, is high or when rival's state, ω_{-i}, is low. Higher own states, i.e. lower unit costs of production, unambiguously imply lower marginal benefits of governance as lower rival's states have no direct impact on these marginal benefits. Second, higher market shares, regardless of whether they arise from an improvement in own or a worsening of rival's state, imply a higher product market cost of governance. Hence, relatively established firms with larger market shares in our model optimally choose weaker governance simply because their stakes in the product market are higher, i.e. they have more to lose from an aggressive output response of their rivals. A straightforward corollary of this finding is that the greater the firm's market share, the weaker the governance that it optimally chooses: formally, $\forall \omega_i, \omega_{-i} \in \Omega^2$, $\alpha^*(\omega_i + 1, \omega_{-i}) - \alpha^*(\omega_i, \omega_{-i}) < 0$, and $\alpha^*(\omega_i, \omega_{-i} + 1) - \alpha^*(\omega_i, \omega_{-i}) > 0$. Importantly, weaker governance arises as an optimal response to either an improvement in own state or a worsening of rival's.

If firm shareholders adapt governance to the competitive position of their firm, i.e. to own and rivals' states, one is naturally led to ask whether and how they adapt their monitoring/control strategies as their firms' or their rivals' state change, i.e. as they advance or fall behind in the industry. Property 3 states that industry leaders optimally choose weaker governance than laggards and their governance is weaker the more ahead they are with respect to laggards. The intuition is analogous to properties 1 and 2: In effect, shareholders of the leading firm face a lower opportunity cost of choosing weaker governance: industry leaders with large market shares in our model optimally choose weaker governance than laggards simply because their stakes in the product market are higher, i.e. they have more to lose from an aggressive output response of their rivals. Moreover, stakes are higher the more ahead leaders are with respect to laggards.

In summary, asymmetries between competitors within an industry give rise to asymmetries in their governance choices, with larger firms optimally choosing weaker governance. In the next section we study how imperfect corporate control changes the dynamic interaction between competitors through its impact on product market outcomes. Since market structure ultimately results from this dynamic interaction between competitors, this allows us to trace the effects of imperfect corporate control on market structure and its evolution over time.

4 Increasing Dominance and Predation

Can industry leaders gain a strategic advantage from the competitive effects of their governance on product markets? The present section provides an affirmative answer to this question and shows that this strategic advantage makes a firm increasingly dominant, i.e. more likely to stay ahead, once ahead. Moreover, it can drive rivals from the market. These results substantiate the central claim of the paper that governance strategies are predatory, in the sense that they give rise to rival-weakening and exit-inducing behavior.

The full-fledged dynamic model outlined in the previous section is likely to be characterized by a set of complicated interactions between the outcome of R&D activity and product market competition. Throughout this section we abstract from endogenous entry and exit and study the case with $n_t = 2$ active firms. Moreover, we employ asymptotic expansions in the discount factor, $(1+r)^{-1}$, to identify and isolate the main forces at work when r is large. Studying the MPE of the industry for extreme values of discounting enables us to provide an explicit characterization of predatory governance within a standard model of competition in strategic substitutes. While there is no guarantee that all relevant interactions are captured in the polar case we consider, i.e. when discounting is sufficiently high, the effects we uncover turn out to be quite intuitive and are likely to operate in the richer and more realistic setting we take up in the next section.

4.1 Increasing dominance

Firm i's current profit from the product market, $\pi^*(\omega_i, \omega_{-i})$, increases with its own state, ω_i, as a higher value of ω_i corresponds to lower own unit cost of production and, *ceteris paribus*, larger market share. On the other hand, firm i's profits decrease with its rival's state, ω_{-i}, as a higher value of ω_{-i} corresponds to lower rival's unit cost of production and, *ceteris paribus*, smaller market share. Therefore, firm i has an incentive to undertake more R&D in order to increase ω_i. With imperfect corporate control firms gain a strategic advantage, and hence an additional incentive to undertake R&D, from the competitive effects of their optimal choice of weaker governance on product markets.

To illustrate this point and start building intuition on why this strategic advantage is likely to change firm dynamic incentives to undertake R&D, assume that discounting is high enough, i.e. $(1+r)^{-1}$ is low enough, to reduce our model to the case when only next period profits matter. Recall that every period firms incur R&D expenditures to lower unit costs of production in order to increase their future profits from the product market. If there were no imperfections in corporate control, i.e. if the manager no empire-building tendencies $\left(\frac{\partial B(q_{it}, q_{-it}; \omega_{it})}{\partial q_{it}} = 0\right)$, the incentives of a firm, say firm 1, to invest between any two periods are given by the benefit from moving from point A to point B in the top panel of Figure 1: through successful R&D firm 1 can increase its output and profits, i.e. $q_1^B > q_1^A$ and $\pi_1^B > \pi_1^A$, while its rival, say firm 2, decreases its output and profits, i.e. $q_2^B > q_2^A$ and $\pi_2^B > \pi_2^A$. Successful R&D entails a movement from A to B since by advancing firm 1 lowers its unit cost and, as a result, can credibly produce more for any output choice by the rival. In terminology of Tirole (1988), we see a "top dog" strategy, whereby R&D outcomes make firm 1 tougher, while eliciting softer response from its rivals.

With imperfect corporate control, endogenous governance choices cause additional dynamic effects to come into play. From the bottom panel of Figure 1, if firm 1 reduces its cost, product market equilibrium moves from point A to point C, where firm 1 can produce significantly more, $q_1^C > q_1^B > q_1^A$, and earn much higher profits, $\pi_1^C > \pi_1^B > \pi_1^A$, than in the perfect corporate control case. At the same time, the laggard is greatly disadvantaged: $q_2^C > q_2^B > q_2^A$ and $\pi_2^C > \pi_2^B > \pi_2^A$. Intuitively, advancing in the industry through successful R&D now entails a movement from A to C since 1) with a lower unit cost, in addition to any gain in efficiency, firm 1 optimally chooses weaker governance, thus inducing a further outward shift of its output reaction curve; 2) the rival optimally adapts its governance choices as well, but in the opposite direction, i.e. optimally chooses stronger governance, hence shifting its output reaction curve inward.

In summary, governance gives a strategic advantage to whichever firm that gets ahead in the industry in the form of a more aggressive manager who can marginalize rival managers, and effectively captures the market through the strategic effects of managerial boldness - "empire-building". Ultimately industry leaders harvest the competitive benefits of the strategic advantage arising from their governance. We state this crucial property formally in the next proposition and then argue it has deep implications for the evolution of industry structure.

Proposition 4 $\forall (\omega_i, \omega_{-i}) \in \Omega^2$, *if* $\omega_i > \omega_{-i}$ *and* $\omega_{-i} < \tilde{\omega}_{-i}$, *then* $\Delta_i \alpha (\omega_i, \omega_{-i}) - \Delta_i \alpha (\omega_i, \tilde{\omega}_{-i}) < 0$, *where* $\Delta_i \alpha (\omega_i, \omega_{-i}) \equiv \alpha (\omega_i + 1, \omega_{-i}) - \alpha (\omega_i, \omega_{-i})$.

In words, a straightforward implication of the result 1 established in Proposition 8 is that $\Delta \alpha (\omega_i, \omega_{-i}) < 0$, i.e. when advancing in the industry, the industry leader optimally chooses to further weaken his governance. Moreover, his governance is weaker the more ahead he is with respect to his rivals. Hence, the more he is ahead, the larger a strategic advantage the leader gains from the competitive effects of his governance in the product market. In turn, such a market, naturally, becomes less attractive to firms that fall behind since, due to over-production by the leading firm's manager, the return to R&D falls as their market shares decline.

Thus, our analysis suggests that asymmetries in governance choices tend to further exacerbate the initial asymmetries between competitors. With sufficiently high discounting, we show analytically that, due to its competitive effects on firm profits, imperfect corporate control has a first-order effect on firms' incentives to undertake R&D as it encourages R&D expenditure on the side of the leader and discourages R&D expenditure on the side of the laggard. This provides an explicit analytic characterization of governance as predatory in the sense that it leads to increasing dominance, i.e. it makes a firm that gets ahead more likely to stay ahead.

In what follows we give a heuristic description of our methods and relegate the technical details to the appendix. To characterize the MPE of the industry analytically we study asymptotic expansions of the value and decision functions, $V (\omega_i, \omega_{-i})$ and $x (\omega_i, \omega_{-i})$ as defined in (1) and (2)respectively, in the discount rate around $(1 + r)^{-1} \to 0$. In general, we look for functions $(a_0, a_1, ...)$ such that, for any $(\omega_i, \omega_{-i}) \in \Omega^2$ and $\nu \geq 0$, $a (\omega_i, \omega_{-i})$

can be approximated by a polynomial of the form $a_0(\omega_i, \omega_{-i}) + (1+r)^{-1} a_1(\omega_i, \omega_{-i}) + ... + (1+r)^{-\nu} a_\nu(\omega_i, \omega_{-i})$ when r is large. The particular functions, $a(\omega_i, \omega_{-i})$, we are interested in approximating are the value and decision functions of firm i and $-i$, i.e. $V(\omega_i, \omega_{-i})$, $x(\omega_i, \omega_{-i})$, and $V(\omega_{-i}, \omega_i)$, $x(\omega_{-i}, \omega_i)$ respectively.

Our method is closely related to earlier work of Budd, Harris and Vickers (1993) who, however, limit their analysis to one-dimensional product market rivalry, where firm profits are determined by the difference between its current state and the state of its rival. By contrast, as we will show in the present section, we are able to uncover a novel source of increasing dominance by explicitly modeling product market rivalry as two-dimensional. Our sufficient conditions for increasing dominance are a result of independent interest as, to our knowledge for the first time, they illuminate the importance of explicitly accounting for firm heterogeneity.

4.1.1 First order effects

With sufficiently low discounting, i.e. when r is large, the principal contribution to a firm's incentive to undertake R&D is of order one, and is related to the slope of the firm's profit function: the steeper the slope, the greater the firm's incentive to improve its current position. Formally, Appendix C demonstrates that

$$\begin{aligned} A_1(\omega_i, \omega_{-i}) &= \pi^*(\omega_i + 1, \omega_{-i}) - \pi^*(\omega_i, \omega_{-i}) \equiv \Delta_i \pi(\omega_i, \omega_{-i}) \\ B_1(\omega_i, \omega_{-i}) &= \pi^*(\omega_{-i} + 1, \omega_i) - \pi^*(\omega_{-i}, \omega_i) \equiv \Delta_{-i} \pi(\omega_{-i}, \omega_i) \end{aligned}$$

where firm i $(-i)$'s incentives are denoted by A (B). Consequently, the principal contribution to the difference between the R&D efforts of the two rivals, $A - B$, is of order 1, and is related to $\Delta_i \pi(\omega_i, \omega_{-i}) - \Delta_{-i} \pi(\omega_{-i}, \omega_i)$. In particular, define the joint-profit of the two rivals as $\Pi(\omega_i, \omega_{-i}) = \pi^*(\omega_i, \omega_{-i}) + \pi^*(\omega_{-i}, \omega_i)$. The next proposition states sufficient conditions for increasing dominance:

Proposition 5 $\forall(\omega_i, \omega_{-i}) \in \Omega^2$, *if* $\omega_i > \omega_{-i}$ *and*

$$\Pi(\omega_i + 1, \omega_{-i}) - \Pi(\omega_i, \omega_{-i} + 1) + \Delta_{-i} \pi^*(\omega_i, \omega_{-i}) - \Delta_i \pi^*(\omega_{-i}, \omega_i) > 0$$

then $x^*(\omega_i, \omega_{-i}) > x^*(\omega_{-i}, \omega_i)$.

Proof. *See Appendix C.* ■

The proposition identifies two effects through which the leader, by working harder than the laggard, is more likely to stay ahead once ahead. The first is a "joint-profit" effect, $\Pi(\omega_i + 1, \omega_{-i}) - \Pi(\omega_i, \omega_{-i} + 1) > 0$, analogous to the case of one-dimensional competition studied, for example, in Vickers (1986) and Budd, Harris and Vickers (1993), and to the "efficiency effect" identified in the static case studied, for example, in Gilbert and Newbery (1982) and Tirole (1988). It arises whenever firm profits are relatively insensitive to changes in rivals' position, or more precisely when $\Delta_{-i} \pi^*(\omega_i, \omega_{-i}) - \Delta_i \pi^*(\omega_{-i}, \omega_i) = 0$. In this case, the leader works harder than the laggard if joint industry profits are 'increasing in his lead,' in the sense that they are higher when he his lead widens than when it narrows, i.e. $\Pi(\omega_i+1,\omega_{-i}) > \Pi(\omega_i,\omega_{-i}+1)$. The second is a "cross-profit" effect, $\Delta_{-i}\pi^*(\omega_i,\omega_{-i}) - \Delta_i\pi^*(\omega_{-i},\omega_i) > 0$, which, to the best of our knowledge, is novel to the literature. By studying two-dimensional competition we explicitly allow for non-trivial asymmetries across firms which would not arise in the one-dimensional case. In fact, increasing dominance arises even if there is no joint-profit effect, i.e. when $\Pi(\omega_i+1,\omega_{-i}) - \Pi(\omega_i,\omega_{-i}+1) = 0$, as long as, by widening his lead, the leader hurts the laggard more than the laggard can hurt him by catching up, i.e. $|\Delta_i\pi^*(\omega_{-i},\omega_i)| > |\Delta_{-i}\pi^*(\omega_i,\omega_{-i})|$.

With this machinery in place, we are finally in a position to state formally the central result of this section, namely that there are first-order effects through which imperfect corporate control gives rise to increasing dominance:

Proposition 6 *$\forall(\omega_i,\omega_{-i}) \in \Omega^2$ such that $\omega_i \in [0,\overline{\omega}]$ and $\omega_{-i} \in [0,\overline{\omega}]$, if $\omega_i > \omega_{-i}$ and (for a constant $k<1$)*

$$k(D-\gamma) - 4(c(\omega_i)-\gamma) < \Delta c(\omega_i) + \Delta c(\omega_j) + 2(c(\omega_j)-c(\omega_i)) < (D-\gamma) - 4(c(\omega_i)-\gamma)$$

then $x^*(\omega_i,\omega_{-i}) < x^*(\omega_{-i},\omega_i)$ if $\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} = 0$, while $x^*(\omega_i,\omega_{-i}) > x^*(\omega_{-i},\omega_i)$ if $\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} > 0$.

Proof. *See Appendix C.* ■

The proposition provides a first sense in which we can characterize governance as predatory, in that the strategic advantage industry leaders gain from the competitive effects of their governance makes them increasingly dominant, i.e. more likely to stay ahead of their rivals, once ahead. In particular, it gives sufficient conditions for convergence to always obtain in the benchmark model with perfect corporate control ($\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} = 0$), and, by contrast, increasing dominance to always emerge with imperfect corporate control $\left(\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} > 0\right)$. In words, it states that, in every period, if the initial cost disparity, $c(\omega_j) - c(\omega_i)$, and the subsequent cost reduction, $\Delta c(\omega_i) + \Delta c(\omega_j)$, are not too large, then imperfect corporate control radically changes the nature of competitive interaction. An industry that in the absence of corporate control imperfections is characterized by the laggard having a greater incentive to advance and, hence, by a general tendency for catch-up, with imperfect corporate control witnesses the emergence of a dominant firm. In fact, in the latter case, even though no technological or demand changes occurred in the industry, it is the leader who always works harder than the laggard, hence securing for himself a higher likelihood to stay ahead, once ahead.

In summary, if the technological features of the industry are such that in every period advancements lead to increases in market shares that are not too large, then imperfect corporate control has a first-order impact on firm dynamic incentives to work toward advancing in the industry. In particular, it leads to increasing dominance in industries where, were there no imperfections in corporate control, convergence would always emerge.

4.1.2 Higher order effects

When r is large, while joint- and cross-profit effects are the main forces at work, they hardly exhaust the set of economically relevant contributions to firms' incentive to exert R&D effort. To isolate these higher-order effects, we assume that no first-order effects are operative. Under this assumption, we can provide sufficient conditions for increasing dominance:

Proposition 7 *$\forall (\omega_i, \omega_{-i}) \in \Omega^2$ s.t. $\omega_i > \omega_{-i}$ assume that $\Pi(\omega_i + 1, \omega_{-i}) - \Pi(\omega_i, \omega_{-i} + 1) + \Delta_{-i}\pi^*(\omega_i, \omega_{-i}) - \Delta_i\pi^*(\omega_{-i}, \omega_i) = 0$. Then, if*

$$\Delta_i\pi^*(\omega_i + 1, \omega_{-i}) - \Delta_i\pi^*(\omega_i, \omega_{-i} + 1) > 0$$

then $x^*(\omega_i, \omega_{-i}) > x^*(\omega_{-i}, \omega_i)$.

Proof. *See Appendix C.* ■

The proposition identifies the second-order effect through which the leader, by working harder than the laggard, is more likely to stay ahead, once ahead. Since $\Delta\pi_i^*(\omega_i + 1, \omega_j) - \Delta\pi_i^*(\omega_i, \omega_j + 1)$ can be conveniently expressed as $\Delta_i\Delta_i\pi^*(\omega_i, \omega_{-i}) - \Delta_{-i}\Delta_i\pi^*(\omega_i, \omega_{-i})$, this "marginal profit" effect arises when the leader's marginal profits are more sensitive to him widening his lead than to the laggard narrowing it, i.e. $\Delta_i\Delta_i\pi^*(\omega_i, \omega_{-i}) > \Delta_{-i}\Delta_i\pi^*(\omega_i, \omega_{-i})$.

The final result of this section is that there are second-order effects through which imperfect corporate control gives rise to increasing dominance:

Proposition 8 *$\forall (\omega_i, \omega_{-i}) \in \Omega^2$ such that $\omega_i \in [0, \overline{\omega}]$ and $\omega_{-i} \in [0, \overline{\omega}]$, if $\omega_i > \omega_j$, and (for a constant $k < 1$)*

$$(D - \gamma) - 4(c(\omega_i + 1) - \gamma) > \Delta c(\omega_i + 1) - \Delta c(\omega_i) > k(D - \gamma) - 4(c(\omega_i + 1) - \gamma),$$

then $x^*(\omega_i, \omega_{-i}) < x^*(\omega_{-i}, \omega_i)$ if $\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} = 0$, while $x^*(\omega_i, \omega_{-i}) > x^*(\omega_{-i}, \omega_i)$ if $\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} > 0$.

Proof. *See Appendix C.* ■

The proposition provides a higher-order characterization of governance as predatory, in that the strategic advantage industry leaders gain from the competitive effects of their governance makes them increasingly dominant. In the case when there are no first-order effects, it gives sufficient conditions for convergence to always obtain in the benchmark model with perfect corporate control ($\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} = 0$), and, by contrast, increasing dominance to always emerge with imperfect corporate control $\left(\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} > 0\right)$. In words, it states that, in every period, if the cost reduction from further advancing, $\Delta c(\omega_i + 1)$, and from current advancement, $\Delta c(\omega_i)$, are not too different, then imperfect corporate control radically changes the nature of competitive interaction. In particular, an industry where the laggard would otherwise always work harder than the leader, hence securing for itself a higher probability to catch-up the more behind it is, with imperfect corporate control witnesses the emergence of a dominant firm. In fact, in the latter case, even when there are no first-order effects at work, it is the leader who always works harder than the laggard, hence securing for himself a higher likelihood to stay ahead, once ahead.

4.2 Predation

This section completes our analytical characterization of predatory governance. It provides a second sense in which governance is predatory, in that it drives rivals from the market. To this end, we show that whenever there is the possibility of a rival's exit, the prospect of achieving monopoly status makes the industry leader work harder toward further advancing in the industry, i.e. it induces higher R&D expenditures which in turn increase the rival's probability of exit.

We start by introducing an avoidable cost of staying in the industry, $\phi > 0$, which introduces a possibility of exit by the lagging firm. Suppose firm 2 is the laggard, and denote the state where it finds optimal to exit by $\left(\omega_i^E, \omega_{-i}^E\right)$. Moreover, denote by $V'\left(\omega_i, \omega_{-i}\right)$ and $x'\left(\omega_i, \omega_{-i}\right)$ a firm's value and R&D expenditures in the case with $\phi > 0$. The next proposition states, for the case of high discounting, sufficient conditions for the leader to act predatorily in the sense of increasing its R&D expenditures when facing the possibility of an exiting rival.

Proposition 9 *$\forall \left(\omega_i, \omega_{-i}\right) \in \Omega^2$, if $\omega_i > \omega_{-i}$ and*

$$\Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^* \left(\omega_i^E, \omega_{-i}^E\right) > \pi^* \left(\omega_{-i}^E, \omega_i^E\right)$$

then $x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{*\prime}\left(\omega_{-i}^E, \omega_i^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right) - x^*\left(\omega_{-i}^E, \omega_i^E\right)$.

Proof. *See Appendix C.* ■

The proposition identifies a first-order effect through which the leader, by working harder than the laggard, can predatorily drive the latter from the market. It is a "marginal-profit" effect, $\Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^* \left(\omega_i^E, \omega_{-i}^E\right) > \pi^* \left(\omega_{-i}^E, \omega_i^E\right)$, that arises whenever the leader's marginal profits from further widening its lead are relatively sensitive to changes in rivals' position. More precisely, this effect has a very straightforward intuition since the leader acts predatorily whenever predation pays off in the sense that the leader gains relatively more from further advancing when its rivals exits than when it does not.

The last proposition allows us to state the central result of this section, namely that there are first-order effects through which imperfect corporate control gives rise to predation.

Proposition 10 *$\forall \left(\omega_i, \omega_{-i}\right) \in \Omega^2$ such that $\omega_i \in [0, \overline{\omega}]$ and $\omega_{-i} \in [0, \overline{\omega}]$, if $\omega_i > \omega_{-i}$ and (for a constant $k < 1$)*

$$kD > c\left(\omega_{-i}\right)$$

then $x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{*\prime}\left(\omega_{-i}^E, \omega_i^E\right) < x^*\left(\omega_i^E, \omega_{-i}^E\right) - x^*\left(\omega_{-i}^E, \omega_i^E\right)$ if $\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} = 0$, while $x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{*\prime}\left(\omega_{-i}^E, \omega_i^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right) - x^*\left(\omega_{-i}^E, \omega_i^E\right)$ if $\frac{\partial B(q_i, q_{-i}; \omega_i)}{\partial q_i} > 0$.

Proof. *See Appendix C.* ■

The proposition provides a first-order characterization of governance as predatory, in that the strategic advantage industry leaders gain from the competitive effects of their governance makes them drive rivals from the market. It gives sufficient conditions for predation to always emerge with imperfect corporate control $\left(\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} > 0\right)$ in industries where it would never emerge if there where no corporate control imperfections $(\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i} = 0)$. In words, it states that whenever demand is sufficiently high (with respect to the laggard's costs), imperfect corporate control induces the leader to act predatorily, hence securing itself monopoly status.

We are left to show that the aggressive R&D behavior of the industry leader in turn increases the rival's probability of exit. We take up this task in the following proposition.

Proposition 11 *$\forall \left(\omega_i^E, \omega_{-i}^E\right) \in \Omega^2$ s.t. $\phi = V\left(\omega_{-i}^E, \omega_i^E\right) - \varepsilon$, where $|\varepsilon| > 0$ is sufficiently small, if $\omega_i^E > \omega_{-i}^E$, then there exists a MPE where*

1. *$x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right)$;*

2. *the lagging firm is more likely to exit.*

Proof. See Appendix C. ■

We conclude this section with a summary of some key features of our theory of predation. First, with imperfect corporate control the possibility of rival's exit leads the firm to spend more aggressively in R&D than it would were the rival committed not to exit. This in turn increases the probability that the rival exits. This notion of predation is similar in spirit to Ordover and Willig (1981) who define predation as "a response to a rival that sacrifices part of the profit that could be earned under competitive circumstances, were the rival to remain viable, in order to induce exit and earn consequent additional monopoly profit." However, since unlike in Ordover and Willig (1981) we explicitly take uncertainty into consideration, and adopt a definition of predation which is technically closer to Cabral and Riordan (1997), who "call an action predatory if (1) a different action would increase the likelihood that rivals remain viable; (2) the different action would be more profitable under the counterfactual hypothesis that the rival's viability were unaffected." Hence in our case aggressive R&D expenditures are unprofitable but for their effect on a rival's exit decision. Second, in contrast to the focus of much predation literature (see Bolton, Brodley, and Riordan (2000) for a survey) ours is a model of non-price predation. There have been previous attempts at identifying non-prices predatory strategies, of which perhaps the most prominent example is the raising rivals' cost model of Salop and Scheffman (1983). These earlier attempts have encountered the criticism (see, for example, Brennan (1986)) that actions raising rivals' costs are likely to enhance firm efficiency and, consequently, increased attention by competition authorities to allegations of non-price predation may deter procompetitive activity. However, our model is immune to this criticism as it is widely recognized that these concerns do not apply when a firm engages in non-price predation by abusing judicial or administrative or, as in our context, corporate governance procedures to impede competitors. Finally, by incorporating realistic sources of uncertainty about future profitability, our model is immune to a popular criticism of theories of predation, first articulated in Easterbrook (1981), which holds that uncertainty is likely to discourage any predatory behavior as predation involves undergoing current costs to enjoy highly unlikely and, possibly transitory, monopoly profits. As we further articulate in the next section, this assertion is inaccurate as even in presence of substantial uncertainty the powerful combination of increasing dominance and predation makes the prospective monopoly rents anything but transitory.

5 Numerical Results

This section studies the effect of imperfect corporate control on market structure and its evolution over time. We employ numerical methods to show that predatory governance obtains for general discount rates. We then show that imperfections in corporate control have a sizable adverse impact on product market structure and consumer welfare.

We solve numerically and simulate the full-fledged version of the model described in section 2 with endogenous entry and exit and a realistic discount rate. We contrast its properties with those obtained from solving a benchmark industry with perfect corporate control. As our aim is to isolate the effects of endogenous governance choices, the benchmark differs from our model only along the dimension of managerial objectives: in the benchmark managers have no empire-building tendencies $\left(\frac{\partial B(q_i,q_{-i};\omega_i)}{\partial q_i}=0\right)$ and always choose strict-profit-maximizing output. As a result, the standard Cournot outcome obtains in the product market.

5.1 Parameter values

To characterize the properties of the MPE equilibrium of the industry numerically, we parametrize the primitives of the model: $\pi(\cdot)$, $B(\cdot)$, r, x_e, ϕ, and P, i.e. the demand and cost patterns, managerial preferences, technological opportunities, and the institutional structure of the industry. The appendix contains a description of the algorithm we employed to compute the MPE equilibrium given the chosen parameter values.

Demand and cost patterns determine the profit function, $\pi(\cdot)$. We assume linear inverse demand function, $P(Q)=D-bQ$, where distribution of b is iid uniform on $\left(\underline{b},\overline{b}\right)$ with $E(b)=1$, and exponential marginal cost function, $c(\omega)=e^{-\omega}+\gamma\in[\gamma,\gamma+1]$. We normalize the minimum unit cost of production, γ, to one. We choose the market size parameter, i.e. the demand intercept, D, so as to have at most three active firms in the benchmark model. Consequently, we set the maximum number of active firms in the industry to three.

Managerial preferences are parametrized as $B(q_{it},q_{-it},\omega_{it})=\lambda c(\omega_{it})\,q_{it}$. As we emphasized in Section 2, the congruence parameter λ measures the intensity of the 'empire-building' preference of the manager, i.e. it controls the overall importance of his preference for over-production relative to strict-profit maximization. Recall from our discussion of the first order conditions of optimal governance choices, that the marginal benefit of governance is a direct function of the intensity of 'empire-building' preference of the manager. Consequently, we can choose λ to insure that for every possible equilibrium configuration of the industry, the governance problem is well defined, i.e. it always implies positive (although not necessarily strictly positive) monitoring. In other words, we set λ so as the marginal benefit of governance is always high enough to guarantee $\alpha^*(\omega_i,\omega_{-i})\geq 0$, $\forall(\omega_i,\omega_{-i})\in\Omega^{n_t}$.

Setting $\lambda = 0$ delivers the benchmark model with perfect corporate control.

Technological opportunities are fully described by the properties of the stochastic process that governs transition between states, P. Consistently with key empirical properties of R&D (see, for example, Hall et al. (1986) and Lach and Schankerman (1988), and Cohen (1995) for a survey), we assume that the outcome of the innovative effort is uncertain, i.e. higher R&D increases the likelihood of success, and the process of exploration is incremental in the sense that it takes a relatively long string of successes to complete and deliver profits. Formally, we assume that the firm's efficiency level in the next period, ω', is generated by a controlled Markov process, which depends on the firm's efficiency level in the current period, ω, the firm's R&D expenditures level this period, x, and exogenous factors, ν, in the following way:

$$\begin{aligned} \omega' &= \omega + \tau - \nu, \text{ where} \\ p(\tau) &= \begin{cases} \frac{x}{1+x} & \text{if } \tau = 1 \\ \frac{1}{1+x} & \text{if } \tau = 0 \end{cases}, \text{and } p(\nu) = \begin{cases} \delta & \text{if } \nu = 1 \\ 1-\delta & \text{if } \nu = 0 \end{cases} \end{aligned}$$

A straightforward implication of our parametrization is that the probability of a rise in the firm's efficiency level is a monotonically increasing concave function of the R&D expenditures level, while the probability of the efficiency level falling is a monotonically decreasing convex function of x. These properties are desirable since they ensure uniqueness of the solution to the firm problem (Ericson and Pakes (1995), Doraszelski and Satterthwaite (2003)).

Our chosen parameter value for the rate of depreciation, δ, is standard and implies an equal chance of incurring or not depreciation. Moreover, given this value, normalizing the monopolist's exit state to one, we calculated the upper bound on the state space, $\overline{\omega}$, as the state at which it is not optimal for the monopolist firm to invest anymore. The implied value of $\overline{\omega}$ is 28 (For further details on this procedure see Pakes and McGuire (1994)).

Finally, the "institutional" structure of the industry is described by the common discount rate, $(1+r)^{-1}$, the scrap value, ϕ, and the sunk entry cost, X_e. We choose r to match a standard annual interest rate of 4%. Sunk entry cost is chosen so that on average entry costs are about 1/125th of total production costs within a period. The scrap value is chosen to be half of the sunk entry cost. This, together with our choice of a relatively high entry state ($\omega^E = 4$), ensures that in the benchmark entry is relatively cheap and exit entails a relatively low value. Consequently, there are relatively few opportunities to monopolize the industry due to traditional 'barriers to entry' sources.

Table 1 contains a summary of the chosen parameter values.

Computation To compute the symmetric MPE, we use a variant of the algorithm described in Pakes and McGuire (1994). The algorithm works iteratively. It takes a value function $\tilde{V}(\omega_i, \omega)$ and a policy function $\tilde{x}(\omega_i, \omega)$ as its input and generates updated value and policy functions as its output. Each iteration proceeds as follows: First, we use equation (2) to compute firm 1's R&D strategy $x(\omega_i, \omega)$ taking other firms' R&D strategies,

$\tilde{x}_{-i}(\omega_i, \omega)$ as given. Second, we compute the payoff $V(\omega_i, \omega)$ associated with firm 1 using $x(\omega_i, \omega)$ as its R&D strategy and other firms using $x_{-i}(\omega_i, \omega)$ (see equation (1)). The iteration is completed by assigning $V(\omega_i, \omega)$ to $\tilde{V}(\omega_i, \omega)$.

5.2 Governance, increasing dominance, and predation

This subsection shows that predatory governance obtains for realistic discount rates. Throughout we plot the variables of interest, such as firm value and policy functions, over the state space of the industry when there are only two firms active and there is scope for strictly positive R&D in cost reduction, i.e. until each firm reaches its minimum marginal cost.

5.2.1 Optimal governance

In the previous section, we have argued that the central prediction of our model is that governance varies with industry structure, in the sense that it depends both on own and rivals' position in the industry. Figure 2 illustrates this point by plotting optimal governance choices as a function of the state of the industry. Consistent with our previous discussion, as a firm advances it optimally chooses weaker governance. Moreover, optimal governance is weaker, the further behind is the rival. In addition, relatively small variation in costs ($c_{\max} - c_{\min} = 0.08$) translates into substantial variation in governance choices ($|\alpha_{\max} - \alpha_{\min}| = 1$). In other words, as managers' objective is $(P(Q) - \alpha_i c_i) q_i$, a 7% lower physical cost translates into an effective cost to the manager that is up to 100% lower than the initial cost. This suggests that whichever impact governance might have on R&D expenditures is likely to be quantitatively relevant.

We report the resulting period profit function in Figure 3 and contrast it with the profit function for the benchmark model. In both cases, profits increase as a firm goes ahead in the industry and decrease as its rival advances. However, endogenous governance choices induce a more skewed distribution of profits across industry configurations. It is interesting to observe that endogenous governance changes the product market rewards to cost reduction as it makes firm profits more sensitive to the rival's position. A straightforward measure of this sensitivity is provided by $\Delta^x(\omega_i) = \max_{\omega_{-i}} x(\omega_i, \omega_{-i}) - \min_{\omega_{-i}} x(\omega_i, \omega_{-i})$, so that with governance, $\Delta^x =$(0.96, 0.73, 0.66, 0.62, 0.61, 0.61, 0.61, 0.61) compared to $\Delta^x =$(0.29, 0.25, 0.24, 0.23, 0.23, 0.23, 0.23, 0.23) in the benchmark. In the remainder of this section we show that with realistic discounting this excess sensitivity property shapes the value function, i.e. the maximized discounted net present value of profits, in such a way as to introduce a strategic advantage to cost reduction.

5.2.2 Increasing dominance

To examine the forces that give rise to increasing dominance and predation, notice that the leader's current R&D exceeds the laggard's if and only if $x^*(\omega_i, \omega_{-i}) > x^*(\omega_{-i}, \omega_i)$ for all $\omega_i > \omega_{-i}$ which is equivalent to

$$\Delta_i V(\omega_i, \omega_{-i}) > \Delta_{-i} V(\omega_{-i}, \omega_i)$$

for all $\omega_i > \omega_{-i}$, where $\Delta_i V(\omega_i, \omega_{-i}) = V(\omega_i + 1, \omega_{-i}) - V(\omega_i, \omega_{-i})$ refers to the improvement in firm's value from advancing in the industry. In other words, firms' incentive to undertake R&D is related to the slope of the value function: the steeper the slope, the harder the firm works. In analogy with our analysis in Section 3, this condition can be decomposed as (see Appendix C for details)

$$\tilde{V}(\omega_i + 1, \omega_{-i}) - \tilde{V}(\omega_{-i} + 1, \omega_i) + \Delta_{-i} V(\omega_i, \omega_{-i}) - \Delta_i V(\omega_{-i}, \omega_i) > 0$$

where $\tilde{V}(\omega_i, \omega_{-i}) = V(\omega_i, \omega_{-i}) + V(\omega_{-i}, \omega_i)$ denotes joint value and $\Delta_{-i} V(\omega_i, \omega_{-i}) = V(\omega_i, \omega_{-i} + 1) - V(\omega_i, \omega_{-i})$ is the change in value caused by the rival's advancement. Increasing dominance arises even if there is no "joint-profit" effect, i.e. when $\tilde{V}(\omega_i + 1, \omega_{-i}) - \tilde{V}(\omega_i, \omega_{-i} + 1) = 0$, as long as, by widening his lead, the leader hurts the laggard more than the laggard can hurt him by catching up, i.e. $|\Delta_i V(\omega_{-i}, \omega_i)| > |\Delta_{-i} V(\omega_i, \omega_{-i})|$, a "cross-profit" effect analogous to the one discussed in the previous section.

This "cross-profit" effect is important to understand the marked differences between the benchmark and the case with imperfect corporate control. In the benchmark, managers maximize profits and the product market competition outcome is the familiar linear Cournot-Nash equilibrium. It is apparent from the left panels of Figure 5 that firm value and R&D in this case are simple: more or less irrespective of its opponent's position, a firm value increases and, consequently, the firm undertakes R&D until there is no more room for increasing its market share. In other words, both value function and R&D are "flat" in the opponent's state. Contrast this scenario with the right panels of Figure 5: with imperfect corporate control a firm again undertakes R&D until there is no more room for increasing its market share. However, in marked contrast to the benchmark, its opponent's position in the industry is a key determinant of how hard a firm works to advance. To see this point more precisely, consider the sensitivity of firm 1's R&D to firm 2's state, $\Delta^x(\omega_1) = \max_{\omega_2} x(\omega_1, \omega_2) - \min_{\omega_2} x(\omega_1, \omega_2)$. With imperfect control, Δ^x =(1.55, 3.08, 2.98, 2.39, 1.91, 1.63, 1.42, 1.2, 0.97) compared to Δ^x =(1.3, 0.97, 0.46, 0.21, 0.13, 0.09, 0.07, 0.05, 0.03) in the benchmark.

Due to this excess sensitivity, under governance the firm gains a strategic motive to advance, as it can now deter its rival from advancing. For example, $x(2, -i) = 1.55$ if $-i = 2$, while $\max_{-i<2} x(2, -i) = 1.36$ and $\min_{3 \le -i \le 10} x(2, -i) = 0$; $x(3, -i) = 2.28$ if $-i = 3$, while $\max_{-i<3} x(3, -i) = 3.08$ and $\min_{4 \le -i \le 10} x(3, -i) = 0$; $x(4, -i) = 2.33$ if $-i = 4$, while $\max_{-i<4} x(4, -i) = 3.25$ and $\min_{5 \le -i \le 10} x(4, -i) = 0.27$ (bottom right panel of Figure 5 and Table 7.2). In other words, the industry leader has a strategic advantage over the laggard because the latter's incentive to undertake R&D is very sensitive to the rival's position. In particular, the laggard simply "gives up" if it is sufficiently far behind the leader.

The possibility of gaining a strategic advantage leads to industry dynamics characterized by one firm which eventually gains a position of dominance and drives rivals from the market. This can be seen most clearly by examining the policy function under governance in Tables 7.1 and 7.2. As long as there are symmetric industry structures with no leader and laggard, both firms work harder under governance than in the benchmark. For example, in state $(5,5)$, both firms' R&D expenditure is 2.07 under governance, while it is only 0.97 in the benchmark. On the other hand, once a firm manages to pull ahead and becomes the leader there is a marked drop in the R&D activity of the laggard. Continuing with the above example, if firm 1 pulls even slightly ahead (the industry moves to state $(6,5)$), then firm 2 scales back its R&D expenditures to 1.15 while firm 1 increases its R&D to at 2.36. This tends to further enhance the asymmetry between firms. Moreover, as the industry evolves toward states where the rivals are driven further apart, say $(6,4)$, firm 2 continues to scale back its R&D to 0.56, while firm 1 keeps investing heavily at 2. Hence, firm 2 falls further behind. Eventually in state $(6,3)$ firm 2 gives up and stops investing, hence propelling firm 1 into a position of dominance.

As argued in Section 3, we can establish this "increasing dominance" property by looking at the difference between the R&D of the leader and the laggard. Figure 4.1 plots, for each state (ω_i, ω_j), this difference between the R&D activity of firm i and firm j, $x(\omega_i, \omega_j) - x(\omega_j, \omega_i)$, in the benchmark (left panel) and governance (right panel) models. The benchmark model clearly displays convergence: in any industry state (ω_1, ω_2), $x(\omega_1, \omega_2) - x(\omega_2, \omega_1) < 0$ whenever firm 1 is ahead (states to the right of the diagonal through the state space), i.e the leading firm has a lower incentive to invest than the lagging firm. Conversely, whenever firm 1 is behind (states to the left of the diagonal), this difference is positive, implying that the laggard has a higher incentive to invest than the leader. The governance model, on the other hand, exhibits a wide region of increasing dominance. In particular, except for very asymmetric states ($\omega_i - \omega_j \geq 8$ and, symmetrically, $\omega_j - \omega_i \geq 8$) where the leader is "sufficiently" ahead and has exhausted any potential for cost reduction, in governance equilibrium the leading firm always invests more than the laggard and, consequently, is more likely to stay ahead, once ahead. In Figure 8 we replicate this plot for a number of alternative discount factors. Increasing dominance emerges as a robust feature associated with imperfect corporate control as it obtains for a wide range of discount rates, $(1+r)^{-1}$, between 0.9 and 0.99.

An interesting feature of our computations is that they allow us to quantify the magnitude of the "increasing dominance" property with realistic discounting. In particular, the largest difference between the leader's and the laggard's effort, $\max\left(\max_{\omega_j} x(\omega_i, \omega_j) - x(\omega_j, \omega_i)\right)$, is 3.1 with imperfect corporate control and only 1.1 in the benchmark. To illustrate this, consider state $(3,3)$. Since the likelihood of advancing is an increasing function of effort, by pulling ahead by only one state a firm gains a 65% higher probability of advancing further than its rival. In this sense, we expect imperfections in corporate control to have a quantitatively relevant impact on the structure and evolution of the industry.

A direct implication of the fact that under imperfect control leaders tend to keep their lead is that competition is fiercest when firms are neck-to-neck. In fact it is exactly in these relatively symmetric states that an industry leader emerges and the outcome of competition is decided. To see this we plot the sum of the two firms' R&D efforts, $x(\omega_i, \omega_j) + x(\omega_j, \omega_i)$, in the bottom panels of Figure 4.1 as a measure of the intensity of competition. Clearly, while with imperfect control, holding the combined cost level constant, competition is more intense among firms that are relatively close in the industry than among firms that are far from each others, the reverse is true in the benchmark, where again holding their combined cost level constant, competition is most intense when firms are relatively far from each other.

5.2.3 Predation

Figure 4.2 plots the states at which entry (top panels) and exit (bottom panels) occur. The contrast between the entry and exit states with imperfect corporate control (right panels) and entry and exit states in the benchmark is quite striking. With imperfect control entry only occurs when the incumbent has an $\omega_{-i} \leq 3$, i.e. there are much fewer states at which entry occurs, while exit occurs earlier, i.e. for $\omega_i \leq 2$, and for a wider set of rival's states. We discuss the intuition for these results in turn.

In the benchmark entry occurs for any state of the incumbent. This is a direct consequence of our assumption of relatively low entry costs. In fact, since entry costs are small, the incumbent cannot ever deter entry in the benchmark. By contrast, with imperfect control entry occurs only when the incumbent has a relatively low ω_{-i}. In this case the entrant enters in a relatively symmetric position as, by engaging the incumbent in neck-to-neck completion, it has a reasonable probability of becoming a large dominant player in the future. However, entry does not occur when the incumbent is sufficiently ahead in the industry, i.e. when it has ω_{-i} that are larger than the likely post-entry states of the entrant. In other words, the incumbent can deter entry provided its ω is at least moderately large ($\omega \geq 4$). This is because the potential entrant knows that, upon entry, the established incumbent would both choose governance predatorily and increase its R&D expenditure heavily. In this sense, governance imperfections deter entry despite the fact that entry costs are relatively low.

A direct consequence of our assumption of relatively low scrap value is that, in the benchmark, exit occurs only in state one and only when the rival is relatively ahead in the industry, i.e. for $\omega_{-i} \geq 4$.By contrast, with imperfect control exit occurs earlier, i.e. firms exit also in state two. Moreover, in state one exit occurs irrespectively of the rival's position, i.e. for $\omega_{-i} > 1$. In analogy with the entry decision, a firm exits unless it is in a relatively symmetric position where, by engaging the incumbent in neck-to-neck competition, it has a reasonable probability of becoming a large dominant player in the future. However, exit occurs whenever the incumbent is ahead in the industry, i.e. when it has ω_{-i} that are larger than the likely states of the exiting firm, were it not to exit. In other words, the rival can induce exit provided its ω is at least moderately large ($\omega \geq 4$) if the firm is in state two and it can do so as far as he is ahead if the firm is in state one. This is because the exiting firm knows that, if were it not to exit, the established incumbent would both choose governance predatorily and increase its R&D expenditure heavily. In this sense, governance imperfections induce exit despite the relatively low scrap value.

We conclude this section with some remarks for the skeptics and summarize the key features of our theory of predation within the context of the concerns economists and the courts have typically raised on claims of predation (see Bolton, Brodley, and Riordan (2000) for a careful account of these criticisms). First, in our model during the predatory phase consumers gain from the ensuing intense rivalry. Indeed, with imperfect governance output at any given couple of states is uniformly higher than output that would be produced at the same couple of states in the benchmark with perfect control. Employing a structural model allows us to address the essentially empirical question of whether for realistic parameters the welfare costs of predation offset the welfare benefits of this more intense rivalry. Second, many have questioned whether rivals will remain weakened in the post-predation or recoupment stage. If rivals can bounce back, it has been observed, then predation will be unprofitable and consumers would suffer no concrete welfare losses. In contrast to existing models of predation, we allow for both endogenous entry and exit and we show that governance imperfections have a lasting impact on market structure exactly since they give rise to both entry deterrence and exit inducement. As a result, one observes less entry and a smaller number of active firms with governance imperfections. A further important benefit of allowing for endogenous entry and exit is that even though predation takes place, it is always rational for the prey to enter. Moreover, asymmetries between competitors arise endogenously in our model as a result of the dynamic interaction in the product market and are not postulated at the outset as in much existing literature of predation. This, together with our assumption of realistic uncertainty, allows us to avoid one more controversial aspect of existing predation models, i.e. the counterfactual implication that once successful predation takes place monopoly rents are earned forever after. Lastly, it is often contended that it may be difficult to distinguish harmful predation from beneficial competition. We take up this important issue in our discussion of antitrust policies in conclusion of this section.

5.2.4 Industry evolution

Were there no imperfections in corporate control, the industry would evolve toward symmetric states with two firms active and at a roughly similar efficiency level. A radically different industry structure emerges with imperfect governance, one that is markedly more asymmetric. To illustrate these results, Figure 6 depicts industry structure, i.e. the marginal probability distribution of industry states (ω_i, ω_{-i}), after $T = 5, 25, 50$ periods, starting from state $(0, 0)$. This allows us to study the transitory (short-run) dynamics of the Markov process that drives the equilibrium dynamics of the industry. The figure also contains the distribution of industry states to which the Markov process converges in the long-run, i.e. when T is large enough. By looking at these steady-state dynamics we can detail the long-run impact of imperfect corporate control on industry performance.

As transpires from the left panels of Figure 6, where there no imperfections in corporate control the industry would converge to symmetric states over time. Specifically, state $(7, 7)$ emerges as the mode of the marginal distribution after 25 years and has a probability 0.08, 0.12 after $T = 25, 50$ periods, respectively. While asymmetric states are possible if one firm's R&D fails and the other's succeeds, asymmetric states become less likely over time. For example, states $(8, 6)$ and $(6, 8)$ each have a probability of 0.06, 0.05 after $T = 25, 50$ periods, respectively. This is a direct implication of our convergence results of the previous section: the laggard works harder than the leader to catch up, i.e. $x(6, 8) = 0.72 > 0.47 = x(8, 6)$, hence restoring symmetry.

Imperfections in corporate control have a dramatic impact on industry structure and its evolution. The right panels of Figure 6 reveal that, due to imperfect governance, the industry converges to highly asymmetric structures over time. The industry is relatively symmetric in the early stages of competition, when rivals fiercely battle to get ahead of each other. For example, after $T = 5$ periods the industry is characterized by symmetric states such as $(4, 4)$, $(5, 5)$, $(6, 6)$ with probability of 0.2, 0.2, 0.4 respectively and state $(6, 6)$ is the mode. However, as competition unfolds over time, one firm's R&D fails or the other's succeeds and a leader soon emerges. In contrast to the benchmark, due to our increasing dominance results of the previous section, now the leader works harder than the laggard, hence further deepening any initial asymmetry. For example, after $T = 25$ periods, the monopoly state 8 is the mode, with probability 0.18, and after $T = 50$ periods, the monopoly state 11 is the mode, with probability 0.12. State $(6, 6)$ remains the most likely symmetric state, but it becomes less and less likely over time, as it has probability of 0.16, 0.08 after $T = 25, 50$ periods, respectively. In fact, as soon as an asymmetric state emerges, say, as in the previous example, $(6, 8)$ and $(8, 6)$, the leader works much harder than the laggard, i.e. $x(8, 6) = 1.64 > 0.63 = x(6, 8)$, hence deepening asymmetry.

The fraction of time the Markov process of industry dynamics spends in each state in the long-run is given by the ergodic distribution we plot in the bottom panels of Figure 6. Due to imperfect corporate control, an industry that would otherwise be characterized by a unimodal distribution with mode $(8, 8)$ and fraction of time spent at the mode of 0.037, becomes bimodal with mode $(9, 0)$, i.e. monopoly, and fraction of time spent at the mode of 0.1. There are two striking features of the long-run impact of imperfect governance on the industry: first, in sharp contrast to the benchmark, the industry consists most of the time of a monopolist who, due to the tough competition in the early stages, is relatively more efficient than the duopolists in the benchmark; second, with imperfect corporate control the industry spends a much larger fraction of time in the mode than in the benchmark.

To better understand this last result, consider that regardless of how much time the industry spends in the monopoly states, monopoly positions are not guaranteed to persist indefinitely. Since the modes of the ergodic distribution are contained in a single recurrent set, role reversals must occur from time to time due to the underlying uncertainty inherent in R&D. That governance imperfections have such a distinct adverse impact on industry dynamics stems directly from the fact that they make role reversals particularly unlikely. This is a direct consequence of the fact that governance imperfections increase the gap between the equilibrium payoff of the leading and the lagging firm as shown in the top panels of Figure 5. For example, $V(8, 1) = 50$ in the benchmark while $V(8, 1) = 80$ with endogenous governance. Hence, what is needed for a role reversal is a long string of bad luck for the leader in order to "bring him back to the pack," followed by some good luck for the laggard. This is unlikely to happen.

5.3 Governance, market structure and welfare

In this subsection, we simulate the industry for 10,000 periods using equilibrium value and policy functions and compute, for each industry structure a relatively large sample of observations of firm and industry level variables, such as the number of firms active at every point of time, and their characteristics, such as governance, output, R&D , and entry and exit decisions. This exercise provides a quantitative measure of the long-run impact of corporate governance imperfection on industry performance. Moreover, it enables us to measure the resulting welfare consequences of imperfect corporate control. Our simulations strongly support the conclusion that corporate governance imperfections have a sizable adverse impact on industry structure in the long-run. We finally ask whether our model provides any guidance on the question of what the 'mark' of predatory governance is and which policy instruments can contrast it. In this regard, we argue that an increase in output by an incumbent in response to entry should be deemed predatory and show that an output rule is a highly effective antitrust tool.

5.3.1 Market structure

In the absence of governance imperfections, possibly due to an effective public policy toward governance, the industry would be a 'natural duopoly.' This is apparent from Table 2, which reports that in this case there are two firms active in about 90% of the periods. The industry also displays a relatively high turnover and the average length of time with the same duopolists active is 22 periods. There are periods when one firm falls behind and eventually exits so that its rival earns monopoly profits, but these periods are negligible in the overall history of the industry. In contrast, in the case when there are imperfections in corporate control the industry is radically less competitive as one firm monopolizes it for 95% of the periods. The turnover rate is 8 times smaller than in the benchmark and the average length of time with the same firm monopolizing the industry goes from 2 to 68 periods. As a result, the Herfindahl index almost doubles and is close to one. It is worth emphasizing that, due to the presence of uncertainty and depreciation, any monopolist eventually falls behind sufficiently to induce entry. However, entry is followed by a period of extremely intense competition between relatively symmetric firms which typically lasts until a leader emerges, i.e. until one of the firms manages to pull ahead and gain a position of dominance, and the other gives up and eventually exits. Thus, the major difference between the benchmark and imperfect corporate control models is that in the latter any initial success by one firm in the competitive phase invariably propels that firm into a position of dominance. Notably, with no governance imperfections, an initial success does not lead to dominance by any firm: the firm that falls behind invests heavily as its prospects of future profitability do not worsen dramatically while, on the other hand, the firm that advanced invests less heavily as it faces a very small chance of successfully monopolizing the market and is thus less averse to the prospect of the lagging firm catching up.

A final important remark on Table 2 pertains to R&D expenditures. Whenever there is more than one firm active, average R&D expenditures are much higher under imperfect corporate control than in the benchmark. On the other hand, monopolist firms are 'lazier.' Both phenomena have to do with the fact that with imperfect corporate control competition is fiercer in the symmetric states. Firms engage in heavy R&D expenditures in these early stages of competition and, whenever a leader emerges, it keeps a high level of R&D to maintain its position of dominance. As a result of this substantial R&D effort, once the laggard eventually gives up, the leader finds itself in a relatively more efficient state, i.e. with lower costs, than in the benchmark. This effectively forestalls potential entrants which are discouraged to enter by the prospects of facing aggressive competition.

Table 3 contains detailed information on the characteristics of the resulting product market outcomes, such as sales-weighted average profits, output, market shares, prices, and markups. The most striking feature is that if one takes market structure as given and compares just monopoly periods or just duopoly periods prices are unambiguously *lower* (and output higher) with imperfect corporate control. In particular, whenever a duopoly emerges, fiercer competition under imperfect corporate control translates into profits which are about 30% lower, prices which are about 20% lower, and markups which are about 20% lower than in the benchmark. Monopoly prices are lower as well, reflecting the lower costs of monopolist firms under imperfect control. However, due to governance imperfections, on average prices are about 20% *higher* than in the benchmark. The reason for this apparently paradoxical result is that governance has a significant impact on market structure. In particular, due to governance imperfections, monopoly periods are much more frequent.

In summary, the question of whether we should pursue public policy toward corporate governance is ultimately a question of whether the benefits from having a larger number of firms outweigh the costs from having less efficient and less intensely competing firms.

5.3.2 Welfare

Our analysis so far has focused on positive economic implications of predatory governance, but our theory has a distinct set of normative implications. Schematically, in the short-run consumers derive a static benefit from predatory governance. The static benefit arises since, as shown in Table 3, prices are always lower than in the benchmark for a given market structure. Moreover, whenever there are 2 or more firms active, empire-building managers compete fiercely in the product market and, as a result, prices are substantially lower than in the Cournot outcome. In the long-run, there is a dynamic efficiency gain but also a dynamic market structure cost. The dynamic benefit arises from the incentive governance gives to industry leaders to undertake rival weakening effort. As leaders work harder than in the benchmark, Figure 6 shows that predatory governance involves an efficiency gain with respect to the benchmark as firms have lower costs $\omega \in [5, 13]$ versus $\omega \in [3, 10]$, in the long-run. The market structure cost arises due to the effect governance imperfections have on firm dynamic incentives to undertake R&D and the resulting set of equilibrium states of the industry: since as we have argued so far, due to predatory governance there are fewer firms in the market in the long-run, monopoly power is likely to hurt consumers.

While one could clearly construct examples where the first two effects dominate, making the predatory governance equilibrium better from society's standpoint, the matter of whether predatory governance is beneficial or harmful to society is clearly empirical and cannot be settled on a qualitative basis. An additional advantage of our simulations is that they allow us to compute consumer and producer surplus so as to quantify the welfare implications of predatory governance. Producer surplus is the discounted sum of total profits minus total R&D expenditures and entry costs plus any exit value. Consumer surplus is discounted sum of consumer utility. Table 4 contains the means and standard deviations (within parentheses) of these figures over a thousand separate samples from randomly drawn initial conditions for both the benchmark and model with imperfect corporate control.

The average of the sum of consumer and producer surplus in the benchmark is virtually identical to the case of imperfect corporate control. Thus a social planner whose decisions were based on an unweighted sum of consumer and producer surplus would be indifferent between fostering public policy toward corporate governance and allowing for an institutional environment with governance imperfections. However, the results from the consumer surplus calculations are rather strikingly different. Consumer surplus is on average *significantly lower* with imperfect corporate control, i.e. the difference between the mean in the two models is over five times its standard deviation.

The fact that corporate governance imperfections are so costly to consumers is entirely due to the impact of endogenous governance on dynamic incentives (R&D, entry, and exit). For any given state, in fact, as far as there are two firms active prices are lower and consumer surplus is higher with imperfect governance - the static benefit. However, the equilibrium distribution of states is so much more unfavorable to consumers when governance is imperfect that this effect far outweighs the positive static impact of governance on prices. As a consequence, a social planner who gave more weigh to consumer than to producer surplus would want to pursue public policy toward corporate governance such as the Sarbanes-Oxley Act.

As a final remark, notice that these welfare results obtain within an industry which has low sunk costs relative to demand and, hence, were it not for governance imperfections, would be a natural duopoly. In this sense our calculations indicate that predatory governance can give rise to sizable welfare costs for consumers even in contexts where, due to the lack of entry and re-entry barriers, one would consider predation least likely to arise.

5.3.3 Antitrust analysis: a simple output rule

We have argued throughout that predation is an equilibrium strategy in our model. This result, however, begs two important questions: first, does our theory provide an adequate basis for predation enforcement? In other words, does our theory provide any guidance on which test could be helpful in identifying predatory governance?

Second, is there any implementable antitrust rule which can prove effective against predatory governance? We take up these questions in turn.

An often heard criticism of predation theories that emphasize strategic considerations is that they are unsuitable for judicial use, impossible to implement in court, and based on factual assumptions which are mostly unobservable (see Elzinga and Mills (2001) for a recent example). *Prima facie*, one would suspect that a theory of predation such as ours, with its broad appeal to corporate governance whose features are notoriously hard to pin down empirically, could hardly be immune to this criticism. However, closer inspection of the product market implications of predatory governance reveals that this conclusion is unwarranted and our model provides a remarkably simple test of predation.

To illustrate this point, Figure 3 contrasts equilibrium output choices (top panels) and profits (bottom panels) with and without governance imperfections. The fact that to be able to act predatorily shareholders have to give in to the 'empire-building' tendencies of managers is particularly fortunate from the perspective of antitrust enforcement as it implies that predators leave an unmistakable 'mark' in the product market: as the 'hill' corresponding to the entry states of the rival in the top right panel of Figure 3 strikingly reveals, in response to entry, i.e. when the rival is in state 2 in the Figure, managers of incumbent firms *increase* output beyond the monopoly level, i.e. when the rival is a 'potential entrant' which corresponds to state 1 in the Figure. By rubber stamping managers' output increase decision, the shareholders of the incumbent firm effectively drive a potentially profitable rival from the market. In fact, as it can be seen in the bottom panels of Figure 3, were there no governance imperfections an entrant, which corresponds to state 2 in the Figure, would always be profitable. Not so with governance imperfections, as in this case an entrant always earns zero profits. In this sense, increases in output by incumbents in response to entry are the observable 'mark' of predation and offer a particularly simple test for antitrust enforcement: increases in output by incumbents in response to entry should be deemed predatory.

Output increases provide an objective observable indicator along the lines of the test originally proposed by Oliver Williamson (1977) and adopted by the Department of Transportation in its recently introduced Guidelines (1998) which identify a 'dramatic departure from profit-maximization' as a sufficient test for predation. Williamson's original motivation for this test within an entry deterrence game has been criticized and the credibility of the incumbent's commitment to hold excess capacity before entry has been questioned (see, for example, McGee (1980) and Lott (1999) for a critique of existing predation theories based on the lack of credibility of predatory commitments) on the ground that, once entry does occur, the incumbent finds it optimal to co-operate rather than fight. Our model is by construction immune to this criticism as, by the very nature of our choice of limiting attention to Markov-perfect equilibrium strategies, we rule out firms' ability to commit to entry deterrence strategies. Moreover, by explicitly identifying the firm's predatory strategy that leads to output increases, our model offers, to the best of our knowledge for the first time, a firm strategic rationale for antitrust enforcement that relies on simple objective output increases as a test of predation.

Our test suggests a very simple implementable antitrust rule: incumbent firms should be prohibited from expanding output in response to entry for a period of time sufficient to allow the entrant to advance in the industry, for example, by gaining experience or lowering its costs. Assessing the exact length of the period of time required is an important aspect of implementation of the rule but it is beyond the scope of the present paper and we leave it to future work. While we are not the first to advocate an output increase rule (Williamson (1977) first proposed such a rule within the context of a broader antitrust strategy; Edlin (2001) is a more recent example of a closely related variant), an advantage of our structural approach is that we can evaluate the welfare implications of output increase rules. In particular, we can address the key question of whether an output increase rule can prove effective against predatory governance in the sense of improving consumer welfare. To this end, we computed market structure and welfare statistics for an industry where the antitrust authority imposes an output increase rule along the lines we proposed. Table 7 reports the results of this exercise and contrasts them with the unregulated industry we have considered so far. The main message is that the output increase rule appears to be quite effective at taming predation and mitigating the adverse consequences of governance imperfections for market structure. In particular, the regulated industry witnesses a considerable reduction of the incidence of monopolization, as the percentage of monopoly periods decreases of about 30%. Moreover, the regulated industry is characterized by considerably higher turnover. Importantly, monopolies are much less persistent under regulation, as the average life-span of a monopolist dramatically drops from about 68 to about 6 periods. As it could be expected, these effects translate into tangible gains for consumers as the difference between the mean consumer surplus in the industry with and without regulation is over three times its standard deviation.

Simplicity is an obvious advantage of our proposed output increase rule. However, our analysis falls short from arguing that such a rule is more easily enforceable than some prominent alternatives, such as, for example, a purely cost-based rule in the spirit of Areeda and Turner (1975). There is no reason to believe that the permissible level of output could not be readily calculated by the antitrust authority, but enforcement complications can arise due to the need of forecasting future demand (see Areeda and Turner (1978) for an early exposition of this point). These implementation issues are obviously important but can be addressed satisfactorily only within the context of a broader cost-benefit analysis of alternative rules. While such analysis is beyond the scope of the present paper, we view our results as an encouraging first step toward performing welfare comparison of antitrust rules and leave to future research the obviously important question of carefully assessing the welfare implications of alternative rules within the context of a structural model.

5.3.4 Empirical implications

The distinctive feature of our approach is its emphasis on the simultaneity of real and governance decisions. This enables us to provide an analytic account of the two-way link between a firm's current performance, the characteristics of its rivals, and the features of its governance. This section asks how our results on corporate governance and industry structure compare to the stylized facts of corporate governance (e.g. Gompers, Ishii and Metrick (2003)) and persistent size differences and unchanging leadership within an industry (e.g. Gort (1963), Mueller (1986); see also Caves (1998 for a recent survey). It then articulates on the novel testable implications of our model.

The main mechanism driving our results is that governance is weaker for relatively established incumbent firms with larger market shares, since their shareholders find it optimal to give managers more slack. This mechanism is consistent with the main stylized facts of corporate governance and firm characteristics (e.g. Gompers, Ishii and Metrick (2003), Cremers and Nair (2004)). Using governance data from the Investor Responsibility Research Center and based on 24 distinct corporate-governance provisions, Gompers, Ishii, and Metrick (2003) construct an index by adding one for every provision that reduces shareholders rights, so that higher values of their index mean worse governance. The index is constructed for the 1990s. They find that 1) firms with weaker shareholder right, i.e. weaker governance, tend to be large S&P 500 firms; 2) other things being equal, weaker governance firms have higher capital expenditures than stronger governance firms; 3) the governance index is strongly persistent over time. Our model is broadly consistent with these findings. In particular, the negative correlation between firm size and the quality of governance is a straightforward implication of our main mechanism. Further, as far as R&D expenditures contribute to overall capital expenditures, our results on increasing dominance are consistent with the finding of a negative correlation between capital expenditures and the quality of their governance. Moreover, the wide documented heterogeneity of corporate governance characteristics within industries is easily squared with the wide differences in market shares among firms in our model. Finally, market structure provides a particularly appealing account of the strong persistence of governance features over time as changes in market structure are a low frequency event. An interesting feature of our model is that market structure changes are particularly infrequent since corporate control is imperfect.

Our appeal to imperfections in corporate governance allows us to account for the well documented facts that there are persistent size differences between firms within industries and that industry leadership is persistent as well (see Caves (1998) for a recent survey). Moreover, our increasing dominance results are also consistent with the documented fact that R&D expenditures are positively correlated with firm size. To illustrate the first fact, we compute the contemporaneous correlation, $\rho\left(q\left(\omega_{it},\omega_{-it}\right),q\left(\omega_{-it},\omega_{it}\right)\right)$, between firms' market shares as a measure of the strength of the strategic links between firms in equilibrium. Consistent with our analysis in the previous sections, this contemporaneous correlation is low in the benchmark, as a firm's R&D expenditures are insensitive to its rival's position in the industry, while it is large with imperfect corporate control, as in this case R&D expenditure critically depend on rival's position. The intertemporal correlation, $\rho\left(q\left(\omega_{it},\omega_{-it}\right),q\left(\omega_{it-\tau},\omega_{-it-\tau}\right)\right)$, between a firm's market share at time t and its market share at time $t-\tau$, with $\tau\geq 1$, is a measure of the degree of persistence in a firm's market share. Again, not unexpectedly, past firm market share is a weak predictor of its current share in the benchmark, as the intertemporal correlation declines fast with the lag τ, while it is a strong predictor with imperfect corporate control, as in this case the intertemporal correlation declines slowly with the lag τ. In summary, in the benchmark it is improbable that a firm gains a lasting advantage over its rivals and industry leadership changes hands relatively frequently. By contrast, and more in line with the evidence, predatory governance implies that differences in market shares are persistent and industry leadership long-lasting.

Our model has a number of novel empirically testable implications on the relationship between corporate governance and firm performance. In particular, it can be usefully employed to explain both inter- and intra-industry differences in corporate governance. In fact, it implies that there is an industry factor in corporate governance in the sense that firm governance differs across industries and depends on such industry-level variables as market size and degree of competition. This general implication is consistent with the findings of Aggarwal and Samwick (1999) that a measure of industry concentration, the Herfindahl index, is correlated with an important feature of corporate governance, the extent to which firms give high power incentives to managers through compensation. Aggarwal and Samwick (1999) focus on one particular feature of governance,managerial compensation, while our model has implications for a broader set of governance characteristics. Moreover, they use static models of imperfect product market competition and, hence, take market structure as given. While the link between observable indices of industry structure, such as Herfindahl, and the unobservable extent of product market competition as implied by static models is somewhat tenuous, our model explicitly accounts for the endogeneity of market structure and has direct testable implications on the connection between market concentration and governance. Empirical studies of the effect of the deregulation waves in the 90s on governance (e.g. Kole and Lehn (1997, 1999)) lend further support to our prediction of a link between governance and market structure. These studies focus on particular industries, such as for example the US airline industry, and use a deregulation episode as an exogenous product market or entry shock to test whether firms adapt their governance to changes in market structure. They consider an array of different measures of governance and for some of them, such as for example the size of boards, they document that incumbents' governance actually worsened following deregulation. This finding is broadly consistent with our notion of shareholders adapting governance predatorily.

Our model has a distinct set of predictions concerning the dependence of a firm's governance on firm level variables such as position within the industry, actions of other firms in the industry, and status as entrant, incumbent, or exiting firm. The broad prediction of our model is that firms operating at the core of their industries, i.e. relatively established incumbents, differs substantially in their governance from those at the fringe, i.e. relatively new entrants and firms that are close to leaving their industries. The intriguing empirical question our analysis leaves open is how much of the inter- and intra-industry variation in governance can be explained by market structure and whether most of the variation in governance arises within or between industries. There have been recent attempts in the empirical corporate finance literature (e.g. MacKay and Phillips (2005)) to clarify the link between market structure and financial structure decisions. We conjecture that some of the methods developed within this literature can be usefully employed to test whether proxies for a firm's position within its industry, such as, for example, its "natural hedge, " i.e. its proximity to the median industry profit-to-sales ratio, actions of the other firms in the industry, and its status as entrant, incumbent, or exiting firm, add statistical and economic significance in explaining a firm's governance features such as, for example, CEO turnover, the size of boards, the governance index of Gompers, Ishii, and Metrick (2003).

Finally, our model delivers an important set of implications concerning the impact of governance on firm, and industry, performance. In particular, two central implications of predatory governance, i.e. by adapting their governance relatively established incumbents can induce exit and deter entry are readily testable again by exploiting the analogy with some recent work in the empirical corporate finance literature on firm survival and financial structure (e.g. Zingales (1998)). In particular, in analogy with this literature, one could estimate for a given industry a probit model to empirically test whether own and rivals' governance have any effect on a firm's probability of survival beyond what individual firm efficiency and industry wide conditions would suggest. An entry deterrence test can be built along these lines by estimating for a given industry a probit model linking the probability of entry to the governance of incumbents.

A detailed empirical investigation of both the cross-sectional predictions of the model and the set of predictions on the existence of an industry factor in corporate governance i.e. beyond the scope this paper and we leave this important task for future research. Nevertheless, while none of the stylized facts above constitute a test of our predatory governance model, the key theoretical predictions of the model are broadly in line with the existing evidence.

6 Conclusion

We have introduced imperfect corporate control into a model of dynamic industry equilibrium with imperfect competition (Ericson and Pakes (1995)). We have analyzed the dynamic entry, exit and R&D problem of a firm shareholder faced with the problem of choosing governance to discipline an 'empire-building' manager in charge of product market decisions. We have characterized, both analytically and numerically, the dynamics of the interplay between market structure and endogenous governance by detailing the resulting industry equilibria, entry and exit behavior, and computed welfare consequences.

With free entry and exit, we have shown that the strategic advantage implied by governance leads to market dominance and predation. For realistic industry parameters, these effects were shown to have a sizable impact on market structure. In particular, separation of ownership and control results in lower turnover, higher concentration, and more persistently monopolized markets compared to industries without such separation. By solving the model numerically, we estimated a consequent consumer welfare loss of up to 20 percent. Broadly consistent with stylized facts, we found that older, more established firms tend to have worse governance. We conclude that public policy toward corporate governance can enhance the competitiveness of the industry.

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Appendix A. Strategic Governance

This appendix derives some of the results established in the Section 2 and 3.

Proposition 12 *Manager's optimal output choice is invariant to the choice of empire-building formulation, revenue- or cost-maximizer.*

Proof. *We want to show that, by rescaling parameter λ, we can ensure that manager's output choice remains the same in both formulations.*

1. *If managers care about revenues, then $B(\cdot) = \lambda P(q_{it}, q_{-it})\, q_{it}$, where $\lambda > 0$. In this case, $M(q_{it}, q_{-it}; \omega_{it}) = (1+\lambda) P(q_{it}, q_{-it})\, q_{it} - c(\omega_{it})\, q_{it}$. First order conditions for optimality imply that output choice is given by*

$$(1+\lambda) R_i(q_{it}, q_{-it}) = c(\omega_{it})$$

2. *If managers care about costs, then $B(\cdot) = \lambda c(\omega_{it})\, q_{it}$, where $\lambda > 0$. In this case, $M(q_{it}, q_{-it}; \omega_{it}) = P(q_{it}, q_{-it})\, q_{it} - (1-\lambda) c(\omega_{it})\, q_{it}$. First order conditions for optimality imply that output choice is given by*

$$R_i(q_{it}, q_{-it}) = (1-\lambda) c(\omega_{it})$$

   which is equivalent to

$$\left(1+\tilde{\lambda}\right) R_i(q_{it}, q_{-it}) = c(\omega_{it})$$

   where $\tilde{\lambda} = \frac{\lambda}{1-\lambda}$

■

Proposition 13 *When $n_t = 2$, $\frac{\partial q_i}{\partial \alpha_i} < 0$ and $\frac{\partial q_{-i}}{\partial \alpha_i} > 0$.*

Proof. *Equilibrium in managers' game is characterized by the first order conditions*

$$\frac{\partial M_i}{\partial q_i} = \frac{\partial R_i(q_i, q_j)}{\partial q_i} - \alpha_i c(\omega_i) = 0 \tag{5}$$

and a set of second order conditions

$$\frac{\partial^2 M_i}{\partial q_i^2} = \frac{\partial^2 R_i}{\partial q_i^2} < 0$$

The following condition ensures stability and uniqueness of the symmetric Nash equilibrium in the managers' *game:*

$$A = \frac{\partial^2 M_1}{\partial q_1^2}\frac{\partial^2 M_2}{\partial q_2^2} - \frac{\partial^2 M_1}{\partial q_1 \partial q_2}\frac{\partial^2 M_2}{\partial q_2 \partial q_1} = \frac{\partial^2 R_1}{\partial q_1^2}\frac{\partial^2 R_2}{\partial q_2^2} - \frac{\partial^2 R_1}{\partial q_1 \partial q_2}\frac{\partial^2 R_2}{\partial q_2 \partial q_1} > 0$$

Solution to the (5) *gives us* $q_1 = q(\alpha_1, \alpha_2)$ *and* $q_2 = q(\alpha_2, \alpha_1)$.

To characterize the dependence of q *on* α*'s, we totally differentiate* (5) *w.r.to* q_1, q_2, *and* α_1 *to obtain*

$$\begin{aligned} \frac{\partial^2 M_1}{\partial q_1^2} dq_1 + \frac{\partial^2 M_1}{\partial q_1 \partial q_2} dq_2 &= c(\omega_i)\, d\alpha_1 \\ \frac{\partial^2 M_2}{\partial q_2 \partial q_1} dq_1 + \frac{\partial^2 M_2}{\partial q_2^2} dq_2 &= 0 \end{aligned}$$

Using Cramer's rule, we have that $\frac{\partial q_1}{\partial \alpha_1} = \frac{c(\omega_i)\frac{\partial^2 M_2}{\partial q_2^2}}{A}$. *Since* $\frac{\partial^2 M_2}{\partial q_2^2} < 0$ *and* $A > 0$, $\frac{\partial q_1}{\partial \alpha_1} < 0$. *Similarly,* $\frac{\partial q_2}{\partial \alpha_1} = -\frac{1}{A}\frac{\partial B_i}{\partial q_i}\frac{\partial^2 M_{-i}}{\partial q_{-i}\partial q_i}$. *Since* $\frac{\partial^2 M_{-i}}{\partial q_{-i}\partial q_i} < 0$ *(competition is in strategic substitutes),* $\frac{\partial q_{-i}}{\partial \alpha_i} > 0$. ■

The Linear Cournot Case: $P = D - bQ$

Proposition 14 *With oligopoly,* $\alpha^*(\omega_{it}, \omega_{-it}) < 1$, $\forall i, -i \in N, \forall t$. *With monopoly and perfect competition,* $\alpha^*(\omega_{it}) = 1$, $\forall i, \in N, \forall t$.

Proof. *In the second stage, given* α_i, *firm i's manager maximizes:*

$$\max_{q_i} O_i = \alpha_i \left(D - b\overline{Q} - bq_i - c_i\right) q_i + (1 - \alpha_i)\left(D - b\overline{Q} - bq_i\right) q_i$$

where $\overline{Q} = Q - q_i$. *FOC imply that firm i's best response is given by*

$$R_i\left(\overline{Q}\right) = \frac{D - b\overline{Q} - \alpha_i c_i}{2b}$$

Summing over i, *and denoting* $Q = \sum_i q_i$, *we have*

$$\begin{aligned} Q &= \frac{1}{2b}\left(nD - (n-1)\, bQ - \sum_i \alpha_i c_i\right) \\ Q &= \frac{1}{(n+1)\, b}\left(nD - \sum_i \alpha_i c_i\right) \end{aligned}$$

Plugging this back into FOC and solving for $q^*(\alpha_i, \alpha_{-i})$ *we have*

$$q^*(\alpha_i, \alpha_{-i}) = \frac{1}{(n+1)\, b}\left(D + \sum_{j \neq i} \alpha_j c_j - n\alpha_i c_i\right)$$

Implied equilibrium price and profits are given by

$$\begin{aligned}
p^*(\alpha_i,\alpha_{-i}) &= D-b\frac{1}{(n+1)\,b}\left(nD-\sum_i \alpha_i c_i\right)=\frac{1}{n+1}\left(D+\sum_i \alpha_i c_i\right)\\
\pi^*(\alpha_i,\alpha_{-i}) &= \frac{1}{b\,(n+1)^2}\left(D+\sum_i \alpha_i c_i-(n+1)\,c_i\right)\left(D+\sum_{j\neq i}\alpha_j c_j-n\alpha_i c_i\right)
\end{aligned}$$

In the first stage, firm shareholders choose α_i to maximize $\pi^*(\alpha_i,\alpha_{-i})$. shareholders' FOC of optimality imply that best-response governance choice satisfies:

$$\alpha_i(\alpha_{-i})=\frac{1}{2nc_i}\left(n\,(n+1)\,c_i-(n-1)\left(D+\sum_{j\neq i}\alpha_j c_j\right)\right)$$

Summing over i

$$\begin{aligned}
-2n\sum_i \alpha_i c_i &= n\,(n-1)\,D+(n-1)^2\sum_i \alpha_i c_i-n\,(n+1)\sum_i c_i\\
\sum_i \alpha_i c_i &= \frac{n\,(n+1)}{(n^2+1)}\sum_i c_i-\frac{n\,(n-1)}{(n^2+1)}D
\end{aligned}$$

plugging this back into FOC and solving for α_i we get

$$\alpha_i^*=n-\frac{(n-1)}{c_i\,(n^2+1)}D-\frac{n\,(n-1)}{c_i\,(n^2+1)}\sum_i c_i$$

Notice that a monopolist would always choose $\alpha^*=1$. Moreover, α_i^* does not depend on b.

The resulting equilibrium in the product market, given $(\alpha_1^*,...,\alpha_N^*)$, where $\alpha_i^*=n-\frac{n-1}{c_i(n^2+1)}\left[D+n\sum_i c_i\right]$, results from substituting optimal governance choice into managers' second stage output, $(q_1^*(\alpha_1^*,...,\alpha_N^*)$, ..., $q_N^*(\alpha_1^*,...,\alpha_N^*))$, where (after some algebraic manipulation) each $q_1^*(\alpha_1^*,...,\alpha_N^*)$ is given by

$$q_i=\frac{n}{b\,(n^2+1)}\left(D+n\sum_i c_i-\left(n^2+1\right)c_i\right)$$

implying $p^*=\frac{1}{(n^2+1)}\left(D+n\sum_i c_i\right)$, and, hence, $q_i=\frac{n}{b}\,(p^*-c_i)$. Implied profits are

$$\pi^*=\frac{n}{b}\,(p^*-c_i)^2=\frac{n}{b}\left(\frac{1}{(n^2+1)}\left(D+n\sum_i c_i\right)-c_i\right)^2$$

Finally, we show that, if $c_i=c\ \forall i$, then for $n>1$, it is optimal to pick $\alpha_i<1$ whenever $\alpha_j=1\ \forall j\neq i$. This *holds whenever $D > c$, since, in this case,*

$$\begin{aligned}\alpha_i &= \frac{1}{2}(n+1) - \frac{(n-1)}{2nc}(D + (n-1)c) \\ &= \frac{3}{2} - \frac{1}{2n}\left(1 + \frac{(n-1)D}{c}\right)\end{aligned}$$

and $\alpha_i < 1$ as long as $D > c$. ■

Proposition 15 *Governance equilibrium has the following properties:*

1. $\frac{\partial \alpha^*}{\partial n} > 1$*, i.e. governance improves with competition;*
2. $\alpha < 1$ *iff* $q > 0$;
3. $q_i^C < q_i^*$, $P_i^C > P_i^*$ *and* $\pi_i^C > \pi_i^*$*, i.e. governance equilibrium entails higher production, lower prices, and lower profits than a corresponding Cournot equilibrium.*

Proof. *We provide proof of each of the properties.*

1. *If* $c_i = c \; \forall i$

$$\alpha_i = n - \frac{(n-1)}{c(n^2+1)}D - \frac{n(n-1)}{(n^2+1)}n = \frac{n(n+1)}{(n^2+1)} - \frac{(n-1)}{c(n^2+1)}D$$

Taking the limit

$$\lim_{n \to \infty} \alpha_i = 1$$

2. *To show this property, we proceed in two steps.*

   (a) *First, show that $\alpha < 1$ implies $q > 0$. Suppose $\alpha_i = n - \frac{n-1}{c_i(n^2+1)}\left(D + n\sum_i c_i\right) < 1$. Then*

$$\begin{aligned}n - 1 &< \frac{n-1}{c_i(n^2+1)}\left(D + n\sum_i c_i\right) \\ c_i &< \frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right)\end{aligned}$$

This implies that

$$q_i^* = \frac{n}{b}\left(\frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right) - c_i\right) > 0$$

(b) *Now, suppose that* $q_i^* = \frac{n}{b}\left(\frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right) - c_i\right) > 0$. *Then*

$$\frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right) > c_i$$

This implies that

$$\begin{aligned}
\alpha_i &= n - \frac{n-1}{c_i\,(n^2+1)}\left(D + n\sum_i c_i\right) \\
&< n - \frac{n-1}{\frac{1}{(n^2+1)}\left[D + n\sum_i c_i\right]}\frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right) \\
&< 1
\end{aligned}$$

3. *Compare with Cournot:*

$$\begin{aligned}
q_i^C - q_i^* &= \frac{1}{(n+1)\,b}\left(D + \sum_i c_i\right) - \frac{c_i}{b} - \frac{n}{b}\left(\frac{1}{(n^2+1)}\left(D + n\sum_i c_i\right) - c_i\right) \\
&= \frac{(n-1)}{b}\left(-\frac{D}{(n+1)\,(n^2+1)} - \frac{n^2+n+1}{(n+1)\,(n^2+1)}\sum_i c_i + c_i\right)
\end{aligned}$$

which is negative as long as

$$\begin{aligned}
c_i &< D + \frac{n^2+n+1}{(n+1)\,(n^2+1)}\sum_i c_i \\
D - c_i &> -\frac{n^2+n+1}{(n+1)\,(n^2+1)}\sum_i c_i
\end{aligned}$$

which is true as long as $D > c_i$.

■

Proposition 16 (Optimal governance choice) $\forall \omega_i, \omega_{-i} \in \Omega^2$,

1. *if* $\omega_i > \tilde{\omega}_i$, *then* $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\tilde{\omega}_i, \omega_{-i}) < 0$,

2. *if* $\omega_{-i} < \tilde{\omega}_{-i}$, *then* $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_i, \tilde{\omega}_{-i}) < 0$;

3. *if* $\omega_i > \omega_{-i}$, *then*

   (a) $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) < 0$;

   (b) $\alpha^*(\omega_i + 1, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i + 1) << \alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i)$,

   (c) $\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) << \alpha^*(\omega_i, \omega_{-i} + 1) - \alpha^*(\omega_{-i} + 1, \omega_i)$.

Proof. *As shown above, for the linear Cournot case with* $n = 2$*, we have* $\alpha^*(\omega_i, \omega_{-i}) = 1 - \frac{D+2c(\omega_{-i})-3c(\omega_i)}{5c(\omega_i)}$.

1. *Suppose* $\omega_i > \tilde{\omega}_i$*. Then,*

$$\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\tilde{\omega}_i, \omega_{-i}) = \frac{D + 2c(\omega_{-i})}{5}\left(-\frac{1}{c(\omega_i)} + \frac{1}{c(\tilde{\omega}_i)}\right) < 0$$

2. *Suppose* $\omega_{-i} < \tilde{\omega}_{-i}$*. Then,*

$$\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_i, \tilde{\omega}_{-i}) = \frac{2}{5c(\omega_i)}\left(-c(\omega_{-i}) + c(\tilde{\omega}_{-i})\right) < 0$$

3. *Suppose* $\omega_i > \omega_{-i}$*. Then,*

   (a)

$$\begin{aligned}\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) &= -\frac{D + 2c(\omega_{-i})}{5c(\omega_i)} + \frac{D + 2c(\omega_i)}{5c(\omega_{-i})} \\ &= \frac{D}{5c(\omega_i)\, c(\omega_{-i})}\left(-c(\omega_{-i}) + c(\omega_i)\right) < 0\end{aligned}$$

   (b)

$$\begin{aligned}&\alpha^*(\omega_i + 1, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i + 1) - \left(\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i)\right) \\ = \; &\frac{D + 2c(\omega_i)}{5}\underbrace{\left(-\frac{1}{c(\omega_i + 1)} + \frac{1}{c(\omega_i)}\right)}_{<0} - \frac{2}{5c(\omega_{-i})}\underbrace{\left(-c(\omega_i + 1) + c(\omega_i)\right)}_{>0} < 0\end{aligned}$$

   (c)

$$\begin{aligned}&\alpha^*(\omega_i, \omega_{-i}) - \alpha^*(\omega_{-i}, \omega_i) - \left(\alpha^*(\omega_i, \omega_{-i} + 1) - \alpha^*(\omega_{-i} + 1, \omega_i)\right) \\ = \; &\frac{2}{5c(\omega_i)}\underbrace{\left(-c(\omega_{-i}) + c(\omega_{-i} + 1)\right)}_{<0} + \frac{D + 2c(\omega_i)}{5}\underbrace{\left(\frac{1}{c(\omega_{-i})} - \frac{1}{c(\omega_{-i} + 1)}\right)}_{<0} < 0\end{aligned}$$

■

Proposition 17 $\forall(\omega_i, \omega_{-i}) \in \Omega^2$ *s.t.* $\omega_i > \omega_j$*, if* $\omega_{-i} < \tilde{\omega}_{-i}$ *then* $\Delta\alpha^*(\omega_i, \omega_{-i}) - \Delta\alpha^*(\omega_i, \tilde{\omega}_{-i}) < 0$*, where* $\Delta\alpha^*(\omega_i, \omega_{-i}) \equiv \alpha^*(\omega_i + 1, \omega_{-i}) - \alpha^*(\omega_i, \omega_{-i})$

Proof. *Pick a state* $(\omega_i, \omega_{-i}) \in \Omega^2$ *s.t.* $\omega_i > \omega_j$*. Using* $\alpha^*(\omega_i, \omega_{-i}) = 1 - \frac{D+2c(\omega_{-i})-3c(\omega_i)}{5c(\omega_i)}$*, we can express*

$\Delta\alpha^*(\omega_i,\omega_{-i}) = -\frac{D+2c(\omega_{-i})}{5c(\omega_i+1)c(\omega_i)}(c(\omega_i)-c(\omega_i+1))$. *Suppose that* $\omega_{-i} < \tilde{\omega}_{-i}$. *Then*

$$\begin{aligned}
& \Delta\alpha(\omega_i,\omega_{-i}) - \Delta\alpha(\omega_i,\tilde{\omega}_{-i}) \\
= & -\frac{D+2c(\omega_{-i})}{5c(\omega_i+1)c(\omega_i)}(c(\omega_i)-c(\omega_i+1)) + \frac{D+2c(\tilde{\omega}_{-i})}{5c(\omega_i+1)c(\omega_i)}(c(\omega_i)-c(\omega_i+1)) \\
= & -\frac{2(c(\omega_i)-c(\omega_i+1))}{5c(\omega_i+1)c(\omega_i)}(c(\omega_{-i})-c(\tilde{\omega}_{-i})) \\
< & \; 0
\end{aligned}$$

since $c(\omega_i)-c(\omega_i+1) > 0$ *and* $c(\omega_{-i}) > c(\tilde{\omega}_{-i})$. ■

Appendix B. Markov Perfect Equilibrium Existence

The model satisfies the following assumptions of Proposition 4 in Doraszelski and Satterthwaite (2003):

1. Boundedness:

   (a) The state space is finite

   (b) Profits are bounded for all ω and all n.

   (c) R&Ds are bounded, i.e. $\overline{x} < \infty$ and $\overline{x}^e < \infty$.

   (d) The distributions of scrap values $F(\cdot)$ and setup costs $F^e(\cdot)$ have continuous and positive densities and bounded supports

   (e) Firms discount future payoffs, i.e., $\beta \in [0,1)$.

2. Continuity of firm n's local income function $h_n(\cdot)$ for all ω and all n.

3. UIC admissibility of the transition function $P(\cdot)$.

Appendix C. Asymptotic Expansions

Proof of Proposition (5)**.** Without loss of generality, consider a reformulation of our setup above, with two firms, $x \in [0,1]$, $p(x) = x$, and $c(x) = \frac{1}{2}x^2$. Holding ω_j constant, the value function of firm i is given by

$$\begin{aligned}
V(\omega_i,\omega_j) &= \pi^*(\omega_i,\omega_j) - c(x) \\
& +\beta\left[\begin{array}{l} p(x_i)(p(x_j)V(\omega_i+1,\omega_j+1) + (1-p(x_j))V(\omega_i+1,\omega_j)) \\ +(1-p(x_i))(p(x_j)V(\omega_i,\omega_j+1) + (1-p(x_j))V(\omega_i,\omega_j)) \end{array}\right]
\end{aligned}$$

Denoting

$$\begin{aligned}
\tilde{V}(\omega_i + 1, \omega_j) &= p(x_j) V(\omega_i + 1, \omega_j + 1) + (1 - p(x_j)) V(\omega_i + 1, \omega_j) \\
\tilde{V}(\omega_i, \omega_j) &= p(x_j) V(\omega_i, \omega_j + 1) + (1 - p(x_j)) V(\omega_i, \omega_j)
\end{aligned}$$

we can rewrite the value function as

$$V(\omega_i, \omega_j) = \pi^*(\omega_i, \omega_j) - c(x) + \beta \left[\tilde{V}(\omega_i, \omega_j) + p(x) \left(\tilde{V}(\omega_i + 1, \omega_j) - \tilde{V}(\omega_i, \omega_j)\right)\right]$$

Optimal R&D choice maximizes the value function and is given by the solution to:

$$c'(x) = \beta \left(\tilde{V}(\omega_i + 1, \omega_j) - \tilde{V}(\omega_i, \omega_j)\right)$$

Denote $\tilde{V}(\omega_i + 1, \omega_j) - \tilde{V}(\omega_i, \omega_j) = \Delta\tilde{V}(\omega_i, \omega_j)$ and define $A(\omega_i, \omega_j) = \beta\Delta\tilde{V}(\omega_i, \omega_j)$ as firm 1's incentive to invest. We then have

$$\begin{aligned}
A(\omega_i, \omega_j) &= \beta\Delta\tilde{V}(\omega_i, \omega_j) \\
V(\omega_i, \omega_j) &= \pi^*(\omega_i, \omega_j) - c(x) + \beta\tilde{V}(\omega_i, \omega_j) + \beta x\Delta\tilde{V}(\omega_i, \omega_j)
\end{aligned}$$

The optimal R&D choice is given by $x = \beta\tilde{\Delta}V(\omega_i, \omega_j) = A(\omega_i, \omega_j)$. Using $x^* = A(\omega_i, \omega_j)$, we can rewrite the value function as

$$V(\omega_i, \omega_j) = \pi^*(\omega_i, \omega_j) + \frac{1}{2} A(\omega_i, \omega_j)^2 + \beta\tilde{V}(\omega_i, \omega_j)$$

Borrowing the methods developed in Budd, Harris and Vickers (1993), we take asymptotic expansions in β of $A(\omega_i, \omega_j)$ and $V(\omega_i, \omega_j)$. We write

$$\begin{aligned}
A(\omega_i, \omega_j) &= \sum_{n=0}^{\infty} \beta^n A_n(\omega_i, \omega_j) \\
V(\omega_i, \omega_j) &= \sum_{n=0}^{\infty} \beta^n V_n(\omega_i, \omega_j)
\end{aligned}$$

Note that $\Delta\tilde{V}(\omega_i, \omega_j) = \tilde{V}(\omega_i + 1, \omega_j) - \tilde{V}(\omega_i, \omega_j) = \sum_{n=0}^{\infty} \beta^n \tilde{V}_n(\omega_i + 1, \omega_j) - \sum_{n=0}^{\infty} \beta^n \tilde{V}_n(\omega_i, \omega_j)$, where $\tilde{V}$ are transformations of V.

Substituting the resulting series into the equations for $A(\omega_i, \omega_j)$ and $V(\omega_i, \omega_j)$, and equating terms of same order in β, we get:

$$\begin{aligned} A_0(\omega_i,\omega_j) &= 0 \\ A_1(\omega_i,\omega_j) &= \tilde{V}_0(\omega_i+1,\omega_j) - \tilde{V}_0(\omega_i,\omega_j) \\ V_0(\omega_i,\omega_j) &= \pi^*(\omega_i,\omega_j) \end{aligned}$$

Given that, by symmetry, $B_0(\omega_i,\omega_j) = 0$, we have

$$\begin{aligned} \tilde{V}_0(\omega_i+1,\omega_j) &= V_0(\omega_i+1,\omega_j) \\ \tilde{V}(\omega_i,\omega_j) &= V_0(\omega_i,\omega_j) \end{aligned}$$

and, thus,

$$A_1(\omega_i,\omega_j) = \pi^*(\omega_i+1,\omega_j) - \pi^*(\omega_i,\omega_j)$$

That is, when β is small the principal contribution to firm 1's incentive is of order 1, and it is related to the slope of the firm's profit function: the steeper the slope, the greater the firm's incentive to improve its current position.

Analogously, firm 2's incentive to invest (denoted by B) is given by

$$B_1(\omega_i,\omega_j) = \pi^*(\omega_j+1,\omega_i) - \pi^*(\omega_j,\omega_i)$$

It follows that

$$A - B = \pi^*(\omega_i+1,\omega_j) - \pi^*(\omega_i,\omega_j) - (\pi^*(\omega_j+1,\omega_i) - \pi^*(\omega_j,\omega_i))$$

Overall, the principal contribution to $A-B$ is of order 1, and it is related to $\pi^*(\omega_i+1,\omega_j) - \pi^*(\omega_i,\omega_j) - (\pi^*(\omega_j+1,\omega_i) - \pi^*(\omega_j,\omega_i))$. This effect can be decomposed into joint-profit (Budd, Harris and Vickers (1993)) and "cross-profit" effects :

$$\begin{aligned} & \pi^*(\omega_i+1,\omega_j) - \pi^*(\omega_i,\omega_j) - \pi^*(\omega_j+1,\omega_i) + \pi^*(\omega_j,\omega_i) \\ = \; & \Gamma(\omega_i+1,\omega_j) - \Gamma(\omega_i,\omega_j+1) + \Delta_j\pi^*(\omega_i,\omega_j) - \Delta_i\pi^*(\omega_j,\omega_i) \end{aligned}$$

where $\Gamma(\omega_i,\omega_j) = \pi^*(\omega_i,\omega_j) + \pi^*(\omega_j,\omega_i)$ is the joint profit of the two firms. ■

Proof of Proposition (6). We are trying to show that there are states ω_i and ω_j, $\omega_i > \omega_j$, s.t.

$\Delta\pi^C(\omega_i,\omega_j) < \Delta\pi^C(\omega_j,\omega_i)$ and $\Delta\pi(\omega_i,\omega_j) > \Delta\pi(\omega_j,\omega_i)$. Combining these two inequalities we get:

$$\Delta\pi(\omega_i,\omega_j) - \Delta\pi^C(\omega_i,\omega_j) > \Delta\pi(\omega_j,\omega_i) - \Delta\pi^C(\omega_j,\omega_i) \tag{6}$$

First, substituting equilibrium profit functions for the governance and benchmark models, we can express each of the terms as a function of demand and cost parameters:

$$\begin{aligned}\Delta\pi(\omega_i,\omega_j) &= -\frac{6}{25}\left(c(\omega_i+1)-c(\omega_i)\right)\left(2\left(D+2c(\omega_j)\right)-3\left(c(\omega_i+1)+c(\omega_i)\right)\right)\\ \Delta\pi^C(\omega_i,\omega_j) &= -\frac{4}{9}\left(c(\omega_i+1)-c(\omega_i)\right)\left(D+c(\omega_j)-\left(c(\omega_i+1)+c(\omega_i)\right)\right)\end{aligned}$$

Thus,

$$\Delta\pi(\omega_i,\omega_j) - \Delta\pi^C(\omega_i,\omega_j) = \frac{2\left(c(\omega_i+1)-c(\omega_i)\right)}{225}\left(-4D-58c(\omega_j)+31\left(c(\omega_i+1)+c(\omega_i)\right)\right)$$

By symmetry:

$$\Delta\pi(\omega_j,\omega_i) - \Delta\pi^C(\omega_j,\omega_i) = \frac{2\left(c(\omega_j+1)-c(\omega_j)\right)}{225}\left(-4D-58c(\omega_i)+31\left(c(\omega_j+1)+c(\omega_j)\right)\right)$$

Now we can substitute these expressions into condition (6) to get:

$$4D+58c(\omega_j)-31\left(c(\omega_i+1)+c(\omega_i)\right) > \frac{\Delta c(\omega_j)}{\Delta c(\omega_i)}\left(4D+58c(\omega_i)-31\left(c(\omega_j+1)+c(\omega_j)\right)\right)$$

since $c(\omega_i+1) < c(\omega_i)$. After substituting $c(\omega_i) = e^{-\omega_i}+\gamma$ and simplifying, this condition reduces to

$$\Delta c(\omega_i)+\Delta c(\omega_j)+2\left(c(\omega_j)-c(\omega_i)\right) > \frac{4}{31}(D-\gamma)+4\gamma-4c(\omega_i) \tag{7}$$

This is a necessary condition. We also need to ensure that in these states $\Delta\pi^C(\omega_i,\omega_j) < \Delta\pi^C(\omega_j,\omega_i)$. Using the expression for $\Delta\pi^C(\omega_i,\omega_j)$ above, we can rewrite this as

$$D+c(\omega_j)-\left(c(\omega_i+1)+c(\omega_i)\right) < \frac{\Delta c(\omega_j)}{\Delta c(\omega_i)}\left[D+c(\omega_i)-\left(c(\omega_j+1)+c(\omega_j)\right)\right]$$

After substituting $c(\omega_i) = e^{-\omega_i}+\gamma$ and simplifying, this condition reduces to

$$\Delta c(\omega_i)+\Delta c(\omega_j)+2\left(c(\omega_j)-c(\omega_i)\right) < D-4c(\omega_i)+3\gamma$$

Note that, since $\Delta c(\omega_i) < 0$ and $\Delta c(\omega_j) < 0$, $\Delta c(\omega_i)+\Delta c(\omega_j)+2\left(c(\omega_j)-c(\omega_i)\right)+4c(\omega_i) < 7$, $D+3\gamma \geq 7$ is a sufficient condition for convergence to obtain for all states in the benchmark model.

Combining this with (7), we can define a (non-empty) set of states for which convergence obtains in the benchmark model, while increasing dominance obtains in the endogenous governance model:

$$(D-\gamma)-4\left(c\left(\omega_i\right)-\gamma\right)>\Delta c\left(\omega_i\right)+\Delta c\left(\omega_j\right)+2\left(c\left(\omega_j\right)-c\left(\omega_i\right)\right)>\frac{4}{31}(D-\gamma)-4\left(c\left(\omega_i\right)-\gamma\right)$$

■

Proof of Proposition (7). To verify whether there is any effect over and above the joint profit effect, assume that $\pi^*\left(\omega_i+1,\omega_j\right)-\pi^*\left(\omega_i,\omega_j\right)+\pi^*\left(\omega_j+1,\omega_i\right)-\pi^*\left(\omega_j,\omega_i\right)=0$, or $A_1\left(\omega_i,\omega_j\right)=B_1\left(\omega_i,\omega_j\right)$. Define

$$\begin{aligned} J\left(\omega_i,\omega_j\right) &= V\left(\omega_i+1,\omega_j\right)-V\left(\omega_i,\omega_j\right)-\left(V\left(\omega_j+1,\omega_i\right)-V\left(\omega_j,\omega_i\right)\right) \\ &= \frac{1}{2}A\left(\omega_i+1,\omega_j\right)^2-\frac{1}{2}B\left(\omega_i,\omega_j+1\right)^2-\left(\frac{1}{2}A\left(\omega_i,\omega_j\right)^2-\frac{1}{2}B\left(\omega_i,\omega_j\right)^2\right) \end{aligned}$$

Consider the expansion

$$J\left(\omega_i,\omega_j\right)=\sum_{n=0}^{\infty}\beta^n J_n\left(\omega_i,\omega_j\right)$$

Equate terms of same order in β:

$$\begin{aligned} J_0\left(\omega_i,\omega_j\right) &= 0 \\ J_1\left(\omega_i,\omega_j\right) &= J_0\left(\omega_i,\omega_j\right)=0 \end{aligned}$$

since we know that $A_0\left(\omega_i,\omega_j\right)=B_0\left(\omega_i,\omega_j\right)=0$ and the assumption on joint profits implies that $A_1\left(\omega_i,\omega_j\right)=B_1\left(\omega_i,\omega_j\right)$. Next, add two incentives:

$$A\left(\omega_i,\omega_j\right)-B\left(\omega_i,\omega_j\right)=J\left(\omega_i,\omega_j\right)$$

Equating terms of order 2 in this equation yields

$$A_2\left(\omega_i,\omega_j\right)-B_2\left(\omega_i,\omega_j\right)=J_2\left(\omega_i,\omega_j\right)$$

Returning to the previous eqn and equating terms of order 2

$$J_2\left(\omega_i,\omega_j\right)=\frac{1}{2}A_1\left(\omega_i+1,\omega_j\right)^2-\frac{1}{2}B_1\left(\omega_i,\omega_j+1\right)^2-\left(\frac{1}{2}A_1\left(\omega_i,\omega_j\right)^2-\frac{1}{2}B_1\left(\omega_i,\omega_j\right)^2\right)$$

That is the principal contribution to $A\left(\omega_i,\omega_j\right)-B\left(\omega_j,\omega_i\right)$ comes at second order, and $A\left(\omega_i,\omega_j\right)-B\left(\omega_i,\omega_j\right)>0$ iff joint costs will tend to decrease as the state increases. In fact, we have $A_1\left(\omega_i,\omega_j\right)=B_1\left(\omega_i,\omega_j\right)$, or

$\pi_i^*(\omega_i+1,\omega_j)-\pi^*(\omega_i,\omega_j)=\pi_j^*(\omega_i,\omega_j+1)-\pi_j^*(\omega_i,\omega_j)$. So

$$\begin{aligned}A_2(\omega_i,\omega_j)-B_2(\omega_i,\omega_j) &= J_2(\omega_i,\omega_j)\\ &= \frac{1}{2}A_1(\omega_i+1,\omega_j)^2-\frac{1}{2}A_1(\omega_i,\omega_j+1)^2\\ &= \frac{1}{2}\left[\Delta\pi_i^*(\omega_i+1,\omega_j)-\Delta\pi_i^*(\omega_i,\omega_j+1)\right]\left[\Delta\pi_i^*(\omega_i+1,\omega_j)+\Delta\pi_i^*(\omega_i,\omega_j+1)\right]\end{aligned}$$

If $\Delta\pi$ is positive, then the sign of $A_2(\omega_i,\omega_j)-B_2(\omega_i,\omega_j)$ depends on the sign of

$$\Delta\pi_i^*(\omega_i+1,\omega_j)-\Delta\pi_i^*(\omega_i,\omega_j+1)$$

Note that $\Delta\pi_i^*(\omega_i+1,\omega_j)-\Delta\pi_i^*(\omega_i,\omega_j+1)$ can be expressed as $\Delta_{ii}\pi_i^*(\omega_i,\omega_j)-\Delta_{ij}\pi_i^*(\omega_i,\omega_j)$ ■

Proof of Proposition (8)**.** If $\Delta\pi$ is positive, then the sign of $A_2(\omega_i,\omega_j)-B_2(\omega_i,\omega_j)$ depends on the sign of $\Delta\pi_i(\omega_i+1,\omega_j)-\Delta\pi_i(\omega_i,\omega_j+1)$. We require

$$\begin{aligned}\Delta\pi_i(\omega_i+1,\omega_j)-\Delta\pi_i(\omega_i,\omega_j+1) &> 0\\ \Delta\pi_i^C(\omega_i+1,\omega_j)-\Delta\pi_i^C(\omega_i,\omega_j+1) &< 0\end{aligned}$$

Combining

$$\Delta\pi_i(\omega_i+1,\omega_j)-\Delta\pi_i^C(\omega_i+1,\omega_j)>\Delta\pi_i(\omega_i,\omega_j+1)-\Delta\pi_i^C(\omega_i,\omega_j+1) \tag{8}$$

From above, we know that

$$\begin{aligned}\Delta\pi(\omega_i+1,\omega_j) &= \frac{6}{25}\left(c(\omega_i+2)-c(\omega_i+1)\right)\left(3\left(c(\omega_i+2)+c(\omega_i+1)\right)-2\left(D+2c(\omega_j)\right)\right)\\ \Delta\pi^C(\omega_i+1,\omega_j) &= \frac{4}{9}\left(c(\omega_i+2)-c(\omega_i+1)\right)\left[\left(c(\omega_i+2)+c(\omega_i+1)\right)-\left(D+c(\omega_j)\right)\right]\\ \Delta\pi(\omega_i,\omega_j+1) &= \frac{6}{25}\left(c(\omega_i+1)-c(\omega_i)\right)\left(3\left(c(\omega_i+1)+c(\omega_i)\right)-2\left(D+2c(\omega_j+1)\right)\right)\\ \Delta\pi^C(\omega_i,\omega_j+1) &= \frac{4}{9}\left(c(\omega_i+1)-c(\omega_i)\right)\left[\left(c(\omega_i+1)+c(\omega_i)\right)-\left(D+c(\omega_j+1)\right)\right]\end{aligned}$$

Substituting these expressions into condition (8) we get:

$$\begin{aligned}&\Delta c(\omega_i+1)\left[31\left(c(\omega_i+2)+c(\omega_i+1)\right)-4\left(D+c(\omega_j)\right)-54c(\omega_j)\right]\\ > \;&\Delta c(\omega_i)\left[31\left(c(\omega_i+1)+c(\omega_i)\right)-4\left(D+c(\omega_j+1)\right)-54c(\omega_j+1)\right]\end{aligned}$$

With exponential cost function $c(\omega_i)=c_0e^{-\omega_i}+\gamma$, this condition reduces to

$$\Delta c(\omega_i+1)-\Delta c(\omega_i)>\frac{4}{31}(D-\gamma)-4\left(c(\omega_i+1)-\gamma\right)$$

This is a necessary condition. We also need to ensure that in these states $\Delta\pi_i^C(\omega_i+1,\omega_j) < \Delta\pi_i^C(\omega_i,\omega_j+1)$. Using the expression for $\Delta\pi^C(\omega_i,\omega_j)$ above, we can rewrite this as

$$c(\omega_i+2)+c(\omega_i+1)-(D+c(\omega_j)) > \frac{\Delta c(\omega_i)}{\Delta c(\omega_i+1)}\left[c(\omega_i+1)+c(\omega_i)-(D+c(\omega_j+1))\right]$$

since $\Delta c(\omega_i+1)<0$. With exponential cost function $c(\omega_i)=c_0e^{-\omega_i}+\gamma$, this condition reduces to

$$\Delta c(\omega_i+1)-\Delta c(\omega_i) < (D-\gamma)-4(c(\omega_i+1)-\gamma)$$

Note that, since $\Delta c(\omega_i+1)-\Delta c(\omega_i) < 0.4$, $(D-\gamma)-4(c(\omega_i+1)-\gamma) \geq 0.4$ is a sufficient condition for convergence to obtain for all states in the benchmark model.

Together these two conditions imply:

$$(D-\gamma)-4(c(\omega_i+1)-\gamma) > \Delta c(\omega_i+1)-\Delta c(\omega_i) > \frac{4}{31}(D-\gamma)-4(c(\omega_i+1)-\gamma)$$

For all states that satisfy the above condition, convergence obtains in the benchmark model, while increasing dominance obtains in the endogenous governance model. ■

7 Predation

Proposition 18 *There exists a range of states $\left(\omega_i^E,\omega_{-i}^E\right)\in\Omega^2$ s.t. the lagging firm exits in governance model, and not in the benchmark model.*

Proof. Suppose exit by firm 2 occurs only in state $\left(\omega_i^E,\omega_{-i}^E\right)$. Thus, $V'\left(\omega_{-i}^E,\omega_i^E\right)=0$ and $V\left(\omega_{-i}^E+1,\omega_i^E\right)=\pi^*\left(\omega_{-i}^E+1,\omega_i^E\right)-c(x_{-i})+\beta[(pV\left(\omega_{-i}^E+2,\omega_i^E\right)+(1-p)V\left(\omega_{-i}^E+1,\omega_i^E\right))]-\phi$. Suppose the lagging firm were to deviate and stay in, and let A denote the rival's incentive to invest. Under the hypothesis of equilibrium play in future periods, the deviant firm's R&D choice maximizes $\pi^*\left(\omega_{-i}^E,\omega_i^E\right)-c(x_{-i})+\beta p(x_{-i})V\left(\omega_{-i}^E+1,\omega_i^E\right)$.

Using asymptotic expansions (see proof of the proposition on increasing dominance), we can establish that

$$B_1\left(\omega_{-i}^E,\omega_i^E\right)=\pi^*\left(\omega_{-i}^E+1,\omega_i^E\right)$$

Profit for the deviant firm is given by

$$V_0\left(\omega_{-i}^E,\omega_i^E\right)=\pi^*\left(\omega_{-i}^E+1,\omega_i^E\right)$$

while if the firm exits

$$V\left(\omega_{-i}^E,\omega_i^E\right)=\phi$$

It follows that the equilibrium strategy is to exit at $\left(\omega_i^E, \omega_{-i}^E\right)$ as long as $\pi^* \left(\omega_{-i}^E + 1, \omega_i^E\right) < \phi$.

Now, observe that, as long as $D > 1 \geq c\left(\omega_i^E\right)$, we have

$$\pi^C \left(\omega_{-i}^E + 1, \omega_i^E\right) > \pi^G \left(\omega_{-i}^E + 1, \omega_i^E\right)$$

This follows immediately from substituting the equilibrium profit functions and observing that, at an exit state, $\omega_i^E > \omega_{-i}^E$ and, hence, $\frac{c\left(\omega_{-i}^E+1\right)}{c\left(\omega_i^E\right)} \geq 1$.

We can now establish the following:

- For a given ω_i^E, the equilibrium exit state for firm 2, ω_{-i}^E, satisfies

$$\omega_{-i}^{E(G)} > \omega_{-i}^{E(C)}$$

  since $\Delta_{-i}\pi\left(\omega_{-i}, \omega_i\right) > 0$. In other words, for a given state of the leader, the laggard exits sooner in the governance equilibrium than in the benchmark model.

- For a given ω_{-i}^E, the equilibrium state for firm i that induces firm 2 to exit, ω_i^E, satisfies

$$\omega_i^{E(G)} < \omega_i^{E(C)}$$

  since $\Delta_i\pi\left(\omega_{-i}, \omega_i\right) < 0$. In other words, in any exit state, the efficiency gap between the leader and the laggard is smaller in the governance equilibrium than in the benchmark model.

■

Proposition 19 *There exists a range of states* $\left(\omega_i^E, \omega_{-i}^E\right) \in \Omega^2$ *s.t.*

$$x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{*\prime}\left(\omega_{-i}^E, \omega_i^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right) - x^*\left(\omega_{-i}^E, \omega_i^E\right)$$

and

$$x^{C\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{C\prime}\left(\omega_{-i}^E, \omega_i^E\right) < x^C\left(\omega_i^E, \omega_{-i}^E\right) - x^C\left(\omega_{-i}^E, \omega_i^E\right)$$

Proof. Suppose exit by firm 2 occurs only in state $\left(\omega_i^E, \omega_{-i}^E\right)$. $x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) - x^{*\prime}\left(\omega_{-i}^E, \omega_i^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right) - x^*\left(\omega_{-i}^E, \omega_i^E\right)$ measures the extent to which the leader's R&D exceeds that of the laggard is larger when there's a probability of exit than when no exit is possible (when the rival can commit not to exit).

Using asymptotic expansions (see proof of the proposition on increasing dominance), we can establish that the difference between the leader's and the laggard's incentives to invest in the exit state, denoted A and B, respectively, is determined by

$$A - B = \Delta_i \pi^* (\omega_i, \omega_{-i}) - \Delta_{-i} \pi^* (\omega_{-i}, \omega_i)$$

Since Firm 2 exits in states $\left(\omega_i^E, \omega_{-i}^E\right)$ and $\left(\omega_i^E + 1, \omega_{-i}^E\right)$, $\pi^* \left(\omega_i^E, \omega_{-i}^E\right) = \pi^{*M} \left(\omega_i^E\right)$ and $\pi^* \left(\omega_i^E + 1, \omega_{-i}^E\right) = \pi^{*M} \left(\omega_i^E + 1\right)$, so

$$\begin{aligned} & \left(A\left(\omega_i^E, \omega_{-i}^E\right) - B\left(\omega_i^E, \omega_{-i}^E\right)\right)^{Exit} - \left(A\left(\omega_i^E, \omega_{-i}^E\right) - B\left(\omega_i^E, \omega_{-i}^E\right)\right)^{NoExit} \\ = \; & \Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^* \left(\omega_i^E, \omega_{-i}^E\right) - \pi^* \left(\omega_{-i}^E, \omega_i^E\right) \end{aligned}$$

and this is positive as long as

$$\Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^* \left(\omega_i^E, \omega_{-i}^E\right) > \pi^* \left(\omega_{-i}^E, \omega_i^E\right)$$

The proposition requires that

$$\begin{aligned} \Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^G \left(\omega_i^E, \omega_{-i}^E\right) &> \pi^G \left(\omega_{-i}^E, \omega_i^E\right) \\ \Delta_i \pi^M \left(\omega_i^E\right) - \Delta_i \pi^C \left(\omega_i^E, \omega_{-i}^E\right) &< \pi^C \left(\omega_{-i}^E, \omega_i^E\right) \end{aligned}$$

Summing up

$$\Delta_i \pi^C \left(\omega_i^E, \omega_{-i}^E\right) - \Delta_i \pi^G \left(\omega_i^E, \omega_{-i}^E\right) > \pi^G \left(\omega_{-i}^E, \omega_i^E\right) - \pi^C \left(\omega_{-i}^E, \omega_i^E\right)$$

or,

$$\pi^C \left(\omega_i^E + 1, \omega_{-i}^E\right) - \pi^G \left(\omega_i^E + 1, \omega_{-i}^E\right) > \pi^G \left(\omega_{-i}^E, \omega_i^E\right) - \pi^G \left(\omega_i^E, \omega_{-i}^E\right) + \pi^C \left(\omega_i^E, \omega_{-i}^E\right) - \pi^C \left(\omega_{-i}^E, \omega_i^E\right)$$

In equilibrium with $n = 2$, $\pi^G (\omega_i, \omega_{-i}) = 2 \left(\frac{D - 3c(\omega_i) + 2c(\omega_{-i})}{5}\right)^2$ and $\pi^C (\omega_i, \omega_{-i}) = \left(\frac{D - 2c(\omega_i) + c(\omega_{-i})}{3}\right)^2$. Substituting the profit functions into each of these terms and simplifying, we obtain:

$$\begin{aligned} \pi^G \left(\omega_{-i}^E, \omega_i^E\right) - \pi^G \left(\omega_i^E, \omega_{-i}^E\right) &= \frac{2}{5} \left(c(\omega_i) - c(\omega_{-i})\right) \left(2D - c(\omega_{-i}) - c(\omega_i)\right) \\ \pi^C \left(\omega_i^E, \omega_{-i}^E\right) - \pi^C \left(\omega_{-i}^E, \omega_i^E\right) &= \frac{1}{3} \left(c(\omega_{-i}) - c(\omega_i)\right) \left(2D - c(\omega_i) - c(\omega_{-i})\right) \end{aligned}$$

and

$$\begin{aligned} & \pi^C\left(\omega_i^E+1,\omega_{-i}^E\right)-\pi^G\left(\omega_i^E+1,\omega_{-i}^E\right) \\ = & \frac{\left(D+8c\left(\omega_i+1\right)-7c\left(\omega_{-i}\right)\right)^2+6\left(D-3c\left(\omega_i+1\right)+2c\left(\omega_{-i}\right)\right)\left(D+7c\left(\omega_i+1\right)-8c\left(\omega_{-i}\right)\right)}{(15)^2} \end{aligned}$$

Combining, the three terms and simplifying, we obtain the following inequality

$$\begin{aligned} & \left(\frac{D-8c\left(\omega_i+1\right)+7c\left(\omega_{-i}\right)}{15}\right)^2+2\left(\frac{D-3c\left(\omega_i+1\right)+2c\left(\omega_{-i}\right)}{5}\right)\left(\frac{D+7c\left(\omega_i+1\right)-8c\left(\omega_{-i}\right)}{15}\right) \\ > & \left(2D-c\left(\omega_{-i}\right)-c\left(\omega_i\right)\right)\left(c\left(\omega_i\right)-c\left(\omega_{-i}\right)\right) \end{aligned}$$

Since $\left(c\left(\omega_i\right)-c\left(\omega_{-i}\right)\right)<0$, this inequality is satisfied as long as both of the following hold:

$$\begin{aligned} D-3c\left(\omega_i+1\right)+2c\left(\omega_{-i}\right) &> 0 \\ D+7c\left(\omega_i+1\right)-8c\left(\omega_{-i}\right) &> 0 \end{aligned}$$

The first of these conditions is implied by feasibility (non-zero output) in the governance model: $p^*-c_i>0$ $\Leftrightarrow D-3c\left(\omega_i\right)+2c\left(\omega_{-i}\right)>0$, and $c\left(\omega_i\right)>c\left(\omega_i+1\right)$. Thus, all we need to require is

$$D+7c\left(\omega_i+1\right)>8c\left(\omega_{-i}\right)$$

This is a necessary condition. We also need to ensure that

$$\Delta_i\pi^M\left(\omega_i^E\right)-\Delta_i\pi^C\left(\omega_i^E,\omega_{-i}^E\right)<\pi^C\left(\omega_{-i}^E,\omega_i^E\right)$$

After substituting the profit functions for the benchmark model and simplifying, we get

$$c\left(\omega_i+1\right)\left(-2D+16c\left(\omega_{-i}\right)-7c\left(\omega_i+1\right)\right)<3c\left(\omega_i\right)\left(2D-c\left(\omega_i\right)\right)+4\left(D-2c\left(\omega_{-i}\right)\right)^2$$

which holds as long as $-2D+16c\left(\omega_{-i}\right)-7c\left(\omega_i+1\right)<0$, or

$$D+\frac{7}{2}c\left(\omega_i+1\right)>8c\left(\omega_{-i}\right)$$

Note that this condition also implies the necessary condition above, $D+7c\left(\omega_i+1\right)>8c\left(\omega_{-i}\right)$. In particular, a sufficient condition for this inequality to hold is

$$\frac{1}{8}D>c\left(\omega_{-i}\right)$$

■

Proposition 20 *There exists a range of states* $\left(\omega_i^E, \omega_{-i}^E\right) \in \Omega^2$ *s.t.* $\phi = V\left(\omega_{-i}^E, \omega_i^E\right) - \varepsilon$, *where* $|\varepsilon| > 0$ *is sufficiently small, s.t. in an MPE:*

1. $x^{*\prime}\left(\omega_i^E, \omega_{-i}^E\right) > x^*\left(\omega_i^E, \omega_{-i}^E\right)$, *and*

2. *there is a higher probability that the lagging firm exits in state* $\left(\omega_i^E, \omega_{-i}^E\right)$.

Proof. Suppose exit by firm 2 occurs only in state $\left(\omega_i^E, \omega_{-i}^E\right)$. Suppose the lagging firm were to deviate and stay in one period. Under the hypothesis of equilibrium play in future periods, $V'\left(\omega_{-i}^E, \omega_i^E\right) = 0$ and $V'\left(\omega_{-i}^E + 1, \omega_i^E\right) = V\left(\omega_{-i}^E + 1, \omega_i^E\right) - \phi$. Let y denote the rival's incentive to invest.

We start by showing that $y' > y$, i.e. the rival invests more when there's a probability of exit than when no exit is possible (when the rival can commit not to exit). Using asymptotic expansions (see proof of the proposition on increasing dominance), we can establish that the rival's incentive to invest in the exit state, denoted A, is determined by

$$A_1\left(\omega_i^E, \omega_{-i}^E\right) = \pi^*\left(\omega_i^E + 1, \omega_{-i}^E\right) - \pi^*\left(\omega_i^E, \omega_{-i}^E\right)$$

Since Firm 2 exits in states $\left(\omega_i^E, \omega_{-i}^E\right)$ and $\left(\omega_i^E + 1, \omega_{-i}^E\right)$, $\pi^*\left(\omega_i^E, \omega_{-i}^E\right) = \pi^{*M}\left(\omega_i^E\right)$ and $\pi^*\left(\omega_i^E + 1, \omega_{-i}^E\right) = \pi^{*M}\left(\omega_i^E + 1\right)$ so

$$\begin{aligned} & A_1^{Exit}\left(\omega_i^E, \omega_{-i}^E\right) - A_1^{NoExit}\left(\omega_i^E, \omega_{-i}^E\right) \\ = \; & \Delta_i \pi^M\left(\omega_i^E\right) - \Delta_i \pi^*\left(\omega_i^E, \omega_{-i}^E\right) \\ > \; & 0 \end{aligned}$$

Thus, $y'\left(\omega_i^E, \omega_{-i}^E\right) > y\left(\omega_i^E, \omega_{-i}^E\right)$.

The laggard's payoff from deviating is $V'\left(\omega_{-i}^E, \omega_i^E\right) - \phi$, where

$$V'\left(\omega_{-i}^E, \omega_i^E\right) = \pi^*\left(\omega_{-i}^E, \omega_i^E\right) - c(x) + \beta p(x)\left(V\left(\omega_{-i}^E + 1, \omega_i^E\right) + y'\Delta_i V\left(\omega_{-i}^E + 1, \omega_i^E\right) - \phi\right)$$

On the other hand,

$$V\left(\omega_{-i}^E, \omega_i^E\right) = \pi^*\left(\omega_{-i}^E, \omega_i^E\right) - c(x) + \beta\left(V\left(\omega_{-i}^E, \omega_i^E\right) + y\Delta_i V\left(\omega_{-i}^E, \omega_i^E\right) - \phi\right)$$

Since $\Delta_i V\left(\omega_{-i}^E + 1, \omega_i^E\right) < 0$ (own value is decreasing in rival's state) and $y' - y > 0$, the deviant's payoff from staying in is strictly less than $V\left(\omega_{-i}^E, \omega_i^E\right) - \phi$ by an amount independent of ε. Therefore, it is an equilibrium for the lagging firm to exit in state $\left(\omega_{-i}^E, \omega_i^E\right)$ is ε is sufficiently small. ■

Appendix D. Details of computation

This appendix describes the approach used to solve numerically for the optimal R&D policy once the parameters of the model are set. The solution to the problem of the firm is found using value and policy function iteration method along the lines of Pakes and McGuire (1994). It exploits the computational simplification entailed by the Markov Perfect assumption combined with the recursivity of the optimization problem. The algorithm iterates on the vector containing value functions, V, and the vector of R&Ds, X, (one for each state ω), until the maximum of the element-by-element difference between successive iterations in these vectors is below a pre-specified tolerance level. All computations are carried out in Gauss 3.0.

7.1 Computational algorithm

The algorithm iterates on the V and X matrices until the maximum of the element-by-element difference between successive iterations in these matrices is below a pre-specified tolerance level. The calculations in each iteration are performed separately for each row (industry structure) using only the old values of the matrices V and X. If each element of V and X has converged, then we are assured of having computed a MPNE of the dynamic game.

We describe the process that provides us with new V and X matrices at every iteration. The computation is done separately for each element of V and X. Thus we describe what the algorithm does to $V[\omega, n]$ and $X[\omega, n]$, where ω is the industry vector, and n stands for ω_i, for every $[\omega, n] \in (\Omega^n, N)$. Although we illustrate the updating process for the typical element $[\omega, n]$, this process is done to all possible states $[\omega, n] \in (\Omega^n, N)$.

For a given (ω, n), the values of $V(\omega, n)$ and $X(\omega, n)$ at each new iteration are calculated as follows:

- V: the value function at the k^{th} iteration is written as

$$V^k(\omega, n) = \max \left\{ \begin{array}{c} \phi, \sup_{x \geq 0} A(\omega, n) - x + \beta \sum\limits_{\tau_1=0}^{1} ... \sum\limits_{\tau_N=0}^{1} \sum\limits_{\nu=0}^{1} V^{k-1}(\omega + \tau - \nu, n) \times \\ p\left(\tau_1 | x_1^{k-1}, \nu\right) ..p\left(\tau_h | x, \nu\right) ..p\left(\tau_N | x_N^{k-1}, \nu\right) p(\nu) \end{array} \right\}$$

Denote the firm's expected discounted value for each of the two possible realizations of its R&D process, τ, as

$$CV(z, n) = \beta \left[\begin{array}{c} \sum\limits_{\tau_1=0}^{1} ... \sum\limits_{\tau_{h-1}=0}^{1} \sum\limits_{\tau_{h+1}=0}^{1} ... \sum\limits_{\tau_N=0}^{1} \sum\limits_{\nu=0}^{1} V^{k-1}(z - \nu, n) p(\nu) \times \\ p\left(\tau_1 | x_1^{k-1}, \nu\right) ..p\left(\tau_{h-1} | x_{h-1}^{k-1}, \nu\right) p\left(\tau_{h+1} | x_{h+1}^{k-1}, \nu\right) ..p\left(\tau_N | x_N^{k-1}, \nu\right) \end{array} \right]$$

That is, $CV(\cdot)$ sums over the probability weighted average of the possible states of the future competitors, but not over the investing firm's own future states. Hence, we can rewrite V^k as

$$V^k(\omega,n) = \max\left\{\phi, \sup_{x\geq 0}\left[\begin{array}{c} A(\omega,n) - x + \beta\frac{ax}{1+ax}CV(\omega+e(n),n) \\ +\beta\frac{1}{1+ax}CV(\omega,n)\end{array}\right]\right\} \tag{9}$$

where $e(j)$ is a vector of zeros except for the j^{th} element which is one. Then, whenever $V^k(\omega) \geq \phi$

$$V^k(\omega,n) = \sup_{x\geq 0}\left[A(\omega,n) - x + \beta\frac{ax}{1+ax}CV(\omega+e(n),n) + \beta\frac{1}{1+ax}CV(\omega,n)\right]$$

- X: denote by $x^k(\omega,n)$ the R&D level that solves (**??**), and by D_x the derivative with respect to x. Assuming that R&D is non-zero, and the firm remains active, the optimal R&D $x(\omega,n)$ solves

$$1 = \beta\left[D_x\left(\frac{ax}{1+ax}\right)CV(\omega+e(n),n) + D_x\left(\frac{1}{1+ax}\right)CV(\omega,n)\right]$$
$$1 = \beta\left[D_x\left(\frac{ax}{1+ax}\right)v1 - D_x\left(\frac{ax}{1+ax}\right)v2\right]$$

and $v1 \equiv CV(\omega+e(n),n)$ and $v2 \equiv CV(\omega,n)$. Note that

$$D_x\left(\frac{1}{1+ax}\right) = \frac{a}{(1+ax)^2} = a\left[1-p(x)\right]^2$$

when $\tau = 1$ (and, hence, $p(x) = \frac{ax}{1+ax}$). Thus, $x(\omega,n)$ solves

$$1 = \beta\left[a\left[1-p(x)\right]^2 v1 - a\left[1-p(x)\right]^2 v2\right]$$
$$1 = \beta a\left[1-p(x)\right]^2(v1-v2)$$

Or,

$$\left[1-p(x)\right]^2 = \frac{1}{\beta a(v1-v2)}$$

$$\Longrightarrow p(x) = 1 - \sqrt{\frac{1}{\beta a(v1-v2)}} \tag{10}$$

Taking the inverse of $p(x)$

$$x(\omega,n) = \frac{p(x)}{a-ap(x)}$$

where $p(x)$ is as defined in (10).

- Finally, we can use the derived formula for the optimal R&D to update the value function

$$V^k(\omega,n) = \max\left\{\phi, \sup_{x\geq 0}\left[\begin{array}{c} A(\omega,n) - x(\omega,n) + \beta\frac{ax(\omega,n)}{1+ax(\omega,n)}CV(\omega+e(n),n) \\ +\beta\frac{1}{1+ax(\omega,n)}CV(\omega,n) \end{array}\right]\right\}$$

Note that if $V^k(\omega,n) = \phi$, then R&D is 0 with probability one. Hence, the actual R&D expenditure level is

$$x^k(\omega,n) = \left\{V^k(\omega,n) \geq \phi\right\} x(\omega,n)$$

where $\{\cdot\}$ is the indicator function which takes the value of one when condition inside is satisfied, and zero otherwise.

Appendix E. Figures and Tables

Table 1: Parameter values

Parameter	Description	Value
D	demand intercept	5
δ	rate of depreciation	0.5
ϕ	scrap value	0.1
X_e	sunk entry cost	0.2
β	discount rate	0.96
λ	manager preferences	1.2

Table 2: Market Structure

	No Governance	Governance
% with 1 firm active	3.8	95.2
% with 2 firms active	90.6	4.7
% with 3 firms active	5.6	0.1
$\overline{n}$	2.0	1.0
% with entry and exit	6.0	0.8
% with entry	11.3	1.8
% with exit	11.3	1.8
Total firms in history	1126	179
HHI	0.51	0.98
1/N	0.5	0.95
NVar(ms)	0.01	0.01
NVar(ms)/HHI	9%	1%
Mean lifespan	18.78	42.50
Turnover rate	16.5	2.8
Average length of runs		
1 firm active	1.7	68.1
2 firms active	22.0	6.8
3 firms active	2.3	3.2
R&D		
1 firm active	1.33	0.98
2 firms active	1.64	2.37
3 firms active	2.65	5.57
Average	1.7	1.0
Mean price-cost margin	2.2	2.9
Mean sunk entry inv/output	1%	0.0%

Statistics are computed over 10000 periods (years) starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$. $HHI = \sum_{i=1}^{N} ms_i^2$ is the Herfindahl index of the industry, where ms_i is firm i's market share and N is the number of active firms. Var(ms) is the variance of market shares in the industry. Turnover rate is computed as {(#periods with entry+#periods with exit-#periods with entry and exit)/total #periods * 100}

Parameter values: β=0.96, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Table 3: Prices, Quantities, and Profits

	No Governance	Governance
Profits		
1 firm active	3.19	3.74
2 firms active	1.52	1.07
3 firms active	0.93	0.47
Average	1.55	3.61
Output		
1 firm active	1.83	1.98
2 firms active	2.59	3.06
3 firms active	2.65	3.00
Average	2.57	2.03
Leader's profit share		
1 firm active	1	1
2 firms active	0.56	0.61
3 firms active	0.67	0.60
Average	0.58	0.98
Prices		
1 firm active	3.17	3.01
2 firms active	2.41	1.94
3 firms active	2.35	2.00
Average	2.43	2.96
Markups		
1 firm active	2.49	2.93
2 firms active	2.22	1.72
3 firms active	1.86	1.31
Average	2.21	2.87

Statistics are computed as averages of sales-weighted values over 10000 periods (years) starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$.

Parameter values: β=0.96, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Table 4: Welfare

	No Governance	Governance
Consumer surplus	86.33	55.81
	(7.31)	(6.34)
Producer surplus	20.35	49.94
	(11.14)	(17.27)
Total surplus	106.68	105.75
	(17.41)	(15.47)

The surpluses are the mean and standard deviation (in parentheses) of the discounted sum respective benefits over a one hundred year period averaged over 100 runs starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$.

Parameter values: β=0.96, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Table 5.1: R&D policy $x(\omega_i, \omega_j)$: No Governance

$\omega_1 \backslash \omega_2$	1	2	3	4	5	6	7	8	9	10	Δ^x	$\frac{\Delta^x}{\min_j x(i,j)}$
1	1.3	0.86	0.53	0	0	0	0	0	0	0	1.3	∞
2	1.94	1.74	1.43	1.24	1.13	1.06	1.02	1	0.98	0.97	0.97	1
3	1.63	1.68	1.55	1.43	1.34	1.29	1.26	1.24	1.23	1.22	0.46	0.38
4	1.2	1.28	1.3	1.24	1.19	1.15	1.13	1.11	1.1	1.09	0.21	0.19
5	1	1.02	1.02	1	0.97	0.94	0.92	0.91	0.9	0.89	0.13	0.15
6	0.8	0.8	0.8	0.79	0.77	0.75	0.73	0.72	0.72	0.71	0.09	0.13
7	0.62	0.63	0.63	0.62	0.61	0.59	0.58	0.57	0.57	0.56	0.07	0.13
8	0.49	0.49	0.49	0.48	0.48	0.47	0.46	0.45	0.45	0.44	0.05	0.11
9	0.38	0.38	0.38	0.38	0.37	0.37	0.36	0.36	0.35	0.35	0.03	0.09
10	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.02	0.07

Table 5.2: R&D policy $x(\omega_i, \omega_j)$: Governance

$\omega_1 \backslash \omega_2$	1	2	3	4	5	6	7	8	9	10	Δ^x	$\frac{\Delta^x}{\min_j x(i,j)}$
1	0	0	0	0	0	0	0	0	0	0	0	∞
2	1.36	1.55	0	0	0	0	0	0	0	0	1.55	∞
3	3.08	3.08	2.28	0.87	0	0	0	0	0	0	3.08	∞
4	3.1	3.1	3.25	2.33	1.15	0.56	0.36	0.3	0.28	0.27	2.98	11.0
5	1.95	1.95	1.95	2.84	2.07	1.15	0.68	0.52	0.47	0.45	2.39	5.31
6	1.33	1.33	1.33	2	2.36	1.78	1.03	0.63	0.5	0.46	1.91	4.24
7	0.97	0.97	0.97	1.29	1.87	2.03	1.55	0.9	0.55	0.43	1.63	4.08
8	0.73	0.73	0.73	0.88	1.25	1.64	1.77	1.37	0.78	0.46	1.42	4.06
9	0.56	0.56	0.56	0.63	0.84	1.12	1.43	1.57	1.22	0.68	1.2	3.24
10	0.44	0.44	0.44	0.48	0.59	0.76	0.98	1.25	1.41	1.11	0.97	2.21

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$.
Parameter values: β=0.96, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Table 6.1: Comparative Dynamics - Market Structure

	0.96	0.99	0.97	0.92	0.9	0.85
% with 1 firm active	95.2	99.0	98.8	93.1	90.3	86.1
% with 2 firms active	4.7	1.0	1.2	6.8	8.7	12.6
% with 3 firms active	0.1	0	0	0.1	1.0	1.3
$\overline{n}$	1.05	1.01	1.01	1.07	1.08	1.12
% with entry and exit	0.8	0.3	0.4	3.4	3.4	5.2
% with entry	1.8	0.5	0.9	5.3	6.8	9.0
% with exit	1.8	0.5	0.9	5.3	6.8	9.0
Total firms in history	179	48	90	534	682	900
HHI	0.98	1.00	0.99	0.97	0.95	0.93
Mean lifespan	42.5	79.8	26.4	20.4	16.8	12.9
Average length of runs						
1 firm active	68.1	149.8	108.5	50.6	28.2	15.8
2 firms active	6.8	4.6	6.6	3.7	3.5	3.7
3 firms active	3.2	1.5	2	1.2	1.3	1
Mean R&D	1.0	1.3	1.1	1.0	0.9	0.7
Mean price-cost margin	2.9	3.0	2.9	2.7	2.6	2.5
Mean sunk entry inv/output	0%	0%	0%	1%	1%	1%

Statistics are computed over 10000 periods (years) starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$. $HHI = \sum_{i=1}^{N} ms_i^2$ is the Herfindahl index of the industry, where ms_i is firm i's market share and N is the number of active firms. Var(ms) is the variance of market shares in the industry.

Parameter values: ϕ=0.1, X$_e$=0.2, δ=0.5, D=5

Table 6.2: Comparative Dynamics - Welfare

	0.96	0.99	0.97	0.92	0.9	0.85
No Governance						
Consumer surplus	86.3	217.4	95.2	33.0	24.0	15.5
	(7.3)	(11.6)	(9.2)	(4.3)	(2.8)	(2.4)
Producer surplus	20.4	12.9	21.8	17.5	14.4	11.4
	(11.1)	(27.6)	(11.3)	(5.2)	(4.0)	(2.4)
Total surplus	106.7	230.3	117.1	50.5	38.4	26.9
	(17.4)	(29.5)	(18.3)	(8.2)	(6.1)	(4.3)
Governance						
Consumer surplus	55.8	127.2	64.9	26.1	18.9	12.7
	(6.3)	(5.1)	(10.9)	(2.4)	(0.8)	(0.8)
Producer surplus	49.9	112.3	54.8	25.0	20.8	14.3
	(17.3)	(32.8)	(21.8)	(8.1)	(5.6)	(3.3)
Total surplus	105.8	239.4	119.6	51.1	39.6	26.0
	(15.5)	(31.1)	(16.7)	(7.7)	(6.1)	(3.7)

Statistics are computed over 10000 periods (years) starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$. $HHI = \sum_{i=1}^{N} ms_i^2$ is the Herfindahl index of the industry, where ms_i is firm i's market share and N is the number of active firms. Var(ms) is the variance of market shares in the industry.

Parameter values: ϕ=0.1, X_e=0.2, δ=0.5, D=5

Table 7: Simple Output Rule

	Without output rule	With output rule
% with 1 firm active	95.2	67.3
% with 2 firms active	4.7	32.7
% with 3 firms active	0.1	0
$\overline{n}$	1.05	1.32
Total firms in history	179	2356
Turnover rate	2.8	38.3
Mean lifespan	42.5	6.3
HHI	0.98	0.86
Average length of runs		
1 firm active	68.1	5.6
2 firms active	6.8	2.7
3 firms active	3.2	1.5
Mean R&D	1.0	1.2
Mean price-cost margin	2.9	2.5
Mean sunk entry inv/output	0%	2%
Consumer surplus	55.8	74.7
	(6.3)	(12.8)
Producer surplus	49.9	37.8
	(17.3)	(14.9)
Total surplus	105.8	111.0
	(15.5)	(22.1)

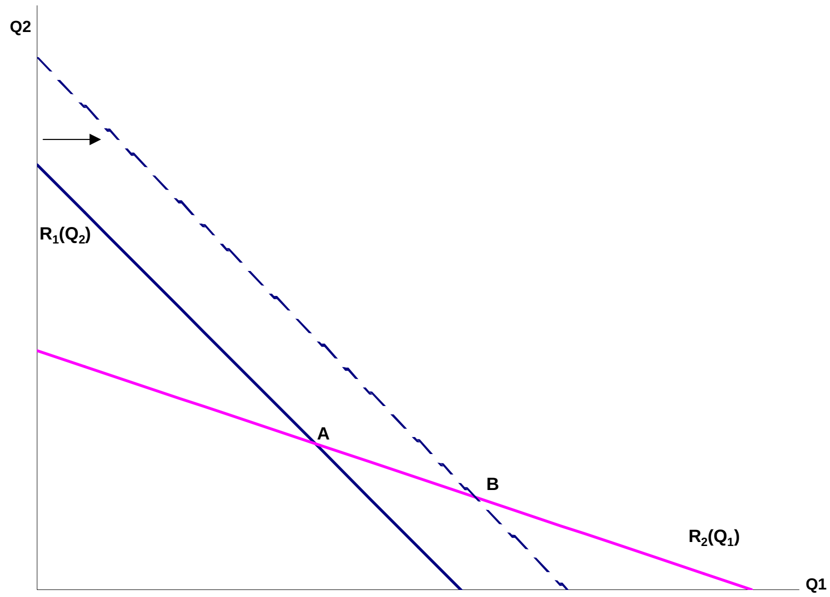
Statistics are computed over 10000 periods (years) starting at random draws from the ergodic distribution of states.

Notation: No Governance refers to Markov-Perfect Nash Equilibrium with $\lambda = 0$. $HHI = \sum_{i=1}^{N} ms_i^2$ is the Herfindahl index of the industry, where ms_i is firm i's market share and N is the number of active firms. Var(ms) is the variance of market shares in the industry.

Parameter values: β=0.96, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Figure 1: Benefit from cost reduction

No Governance



Governance

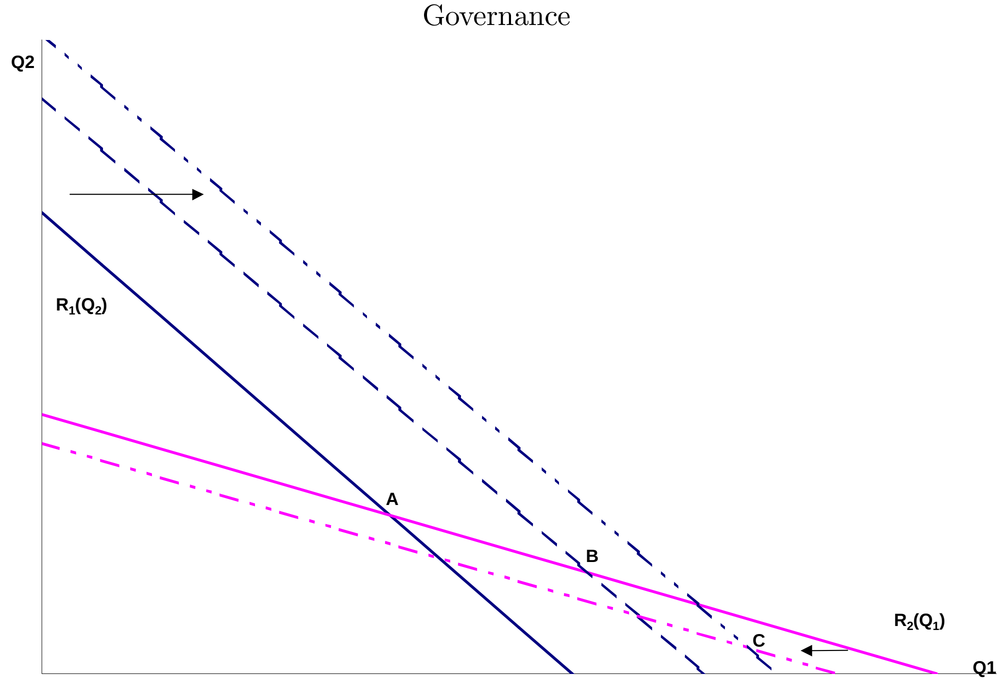
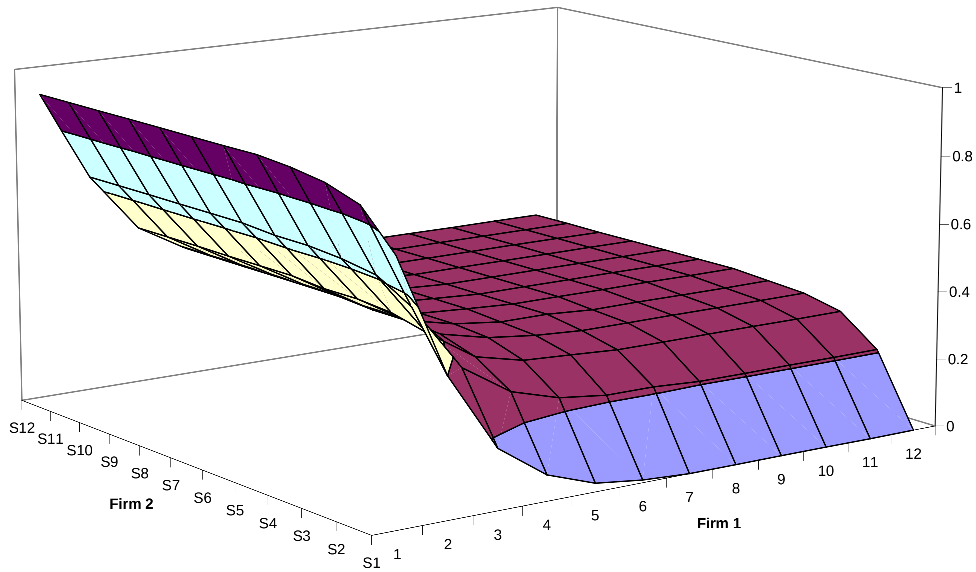


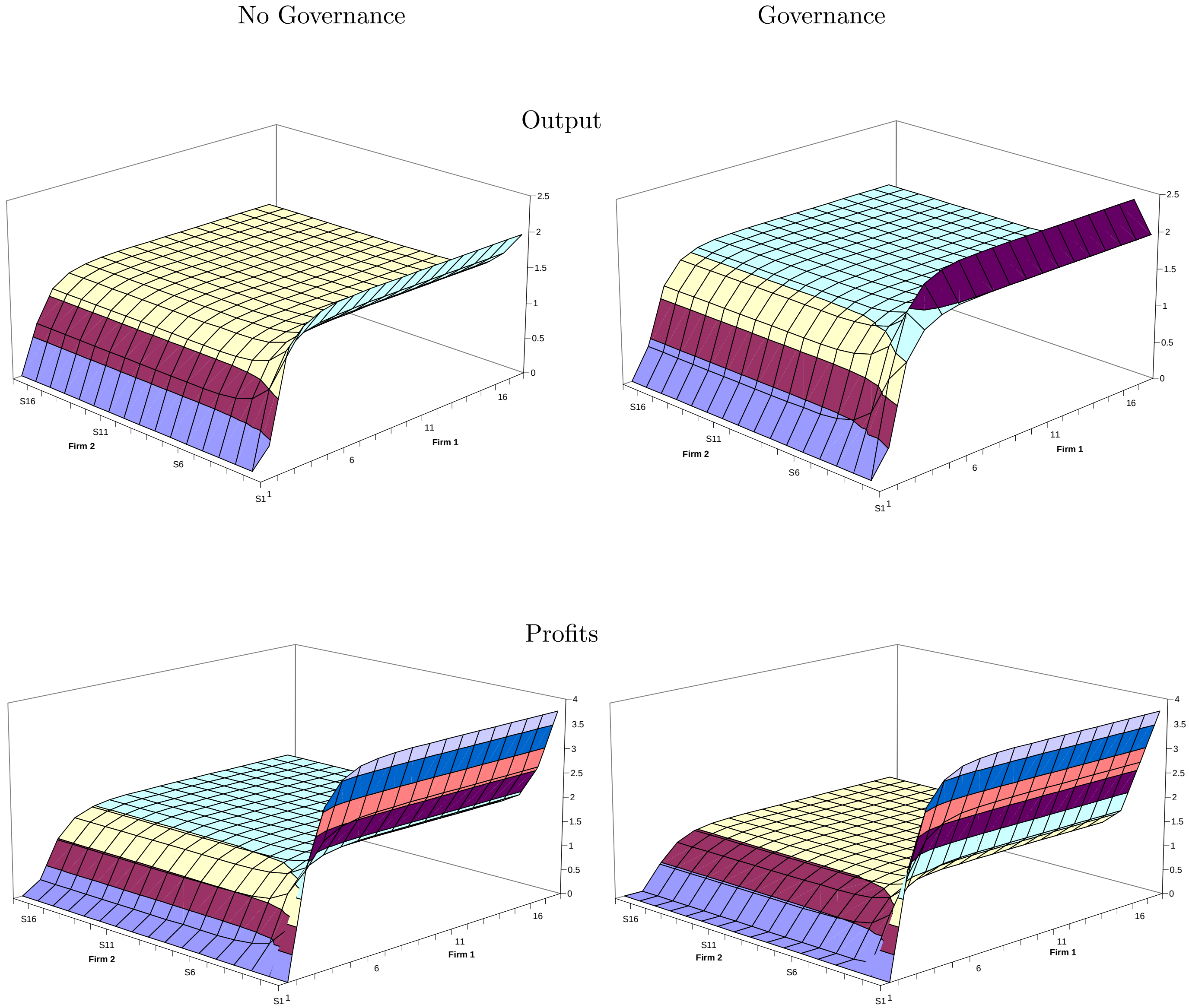
Figure 2: Governance



The graph plots governance choice of Firm 1, $\alpha_1^*(\omega_1, \omega_2)$, as a function of the state of the industry, $\omega = (\omega_1, \omega_2)$, assuming that two firms are active: Firm 1 and Firm 2. Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X$_e$=0.2, δ=0.5, D=5

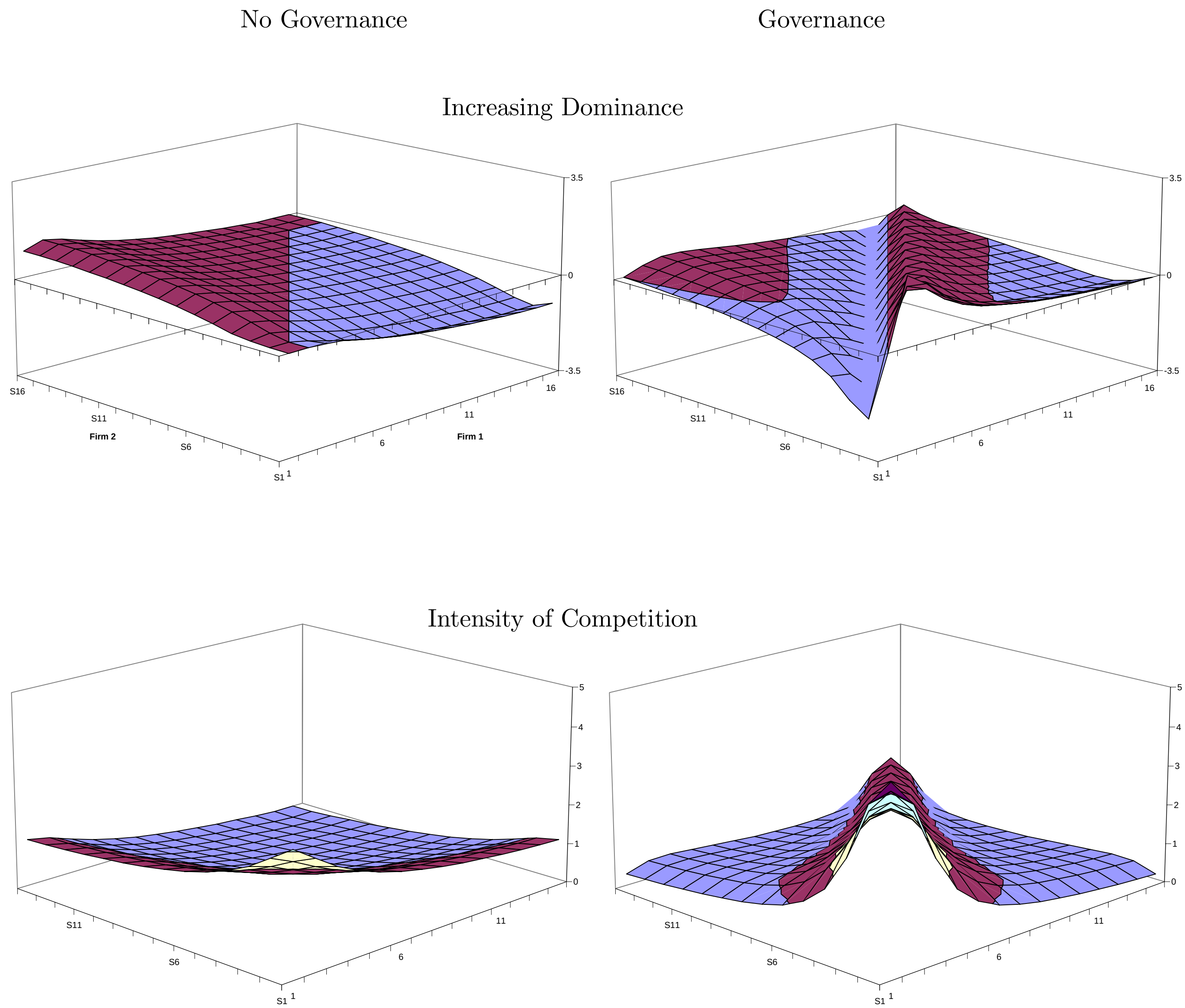
Figure 3: Output and Profits



The graph plots profits of Firm 1, $\pi_1^*(\omega_1, \omega_2)$, as a function of the state of the industry, $\omega = (\omega_1, \omega_2)$, assuming that two firms are active: Firm 1 and Firm 2. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Figure 4.1: Increasing Dominance

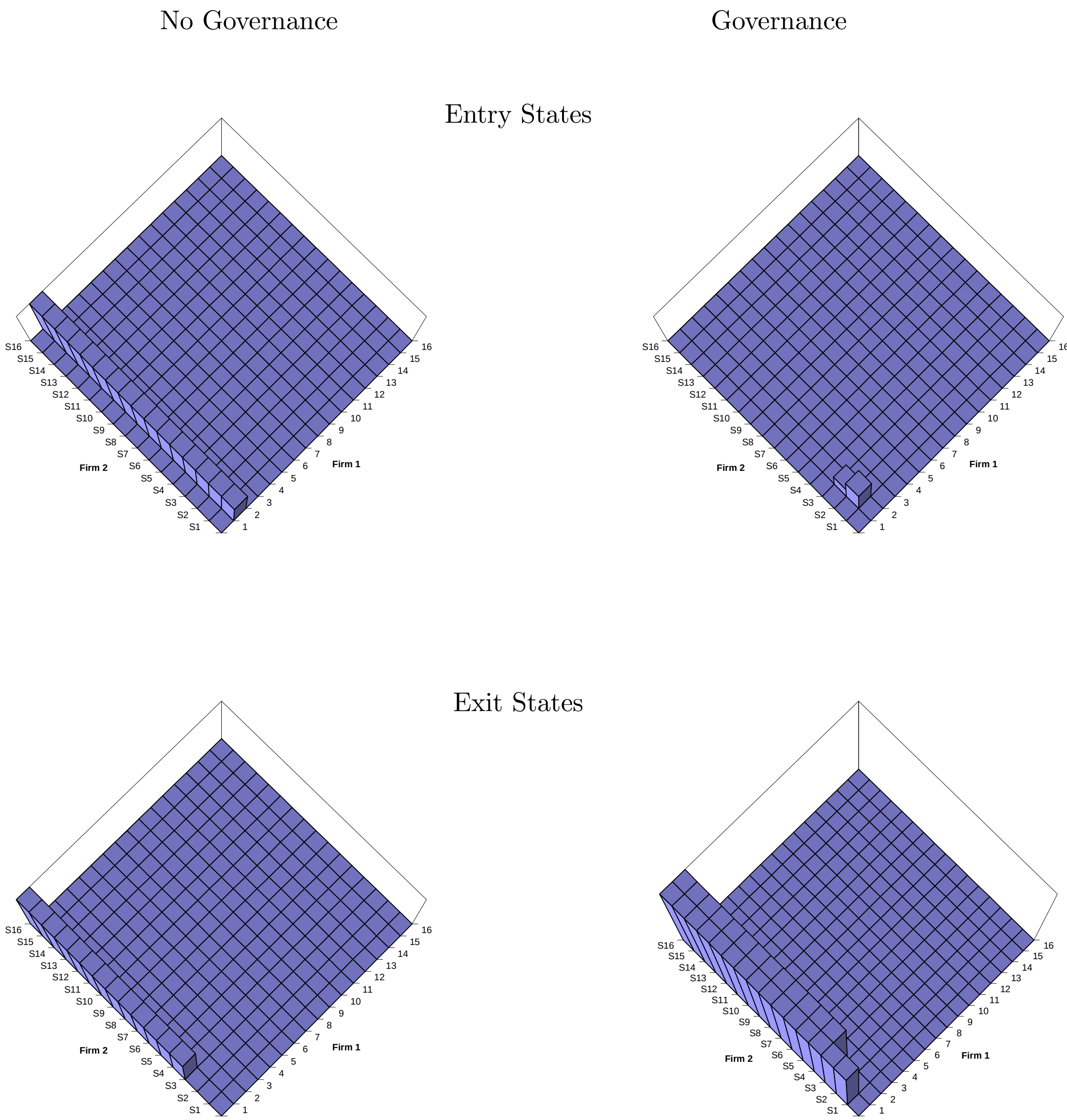


The top two panels plot the difference between R&D activity of Firm 1 and Firm 2, $x(\omega_i - \omega_j) - x(\omega_j - \omega_i)$, as a function of own state and the rival's state, $\omega = (\omega_1, \omega_2)$. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

The bottom two panels plot the sum of the R&D expenditures of Firm 1 and Firm 2, $x(\omega_i - \omega_j) + x(\omega_j - \omega_i)$, as a function of own state and the rival's state, $\omega = (\omega_1, \omega_2)$. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X$_e$=0.2, δ=0.5, D=5

Figure 4.2: Predation

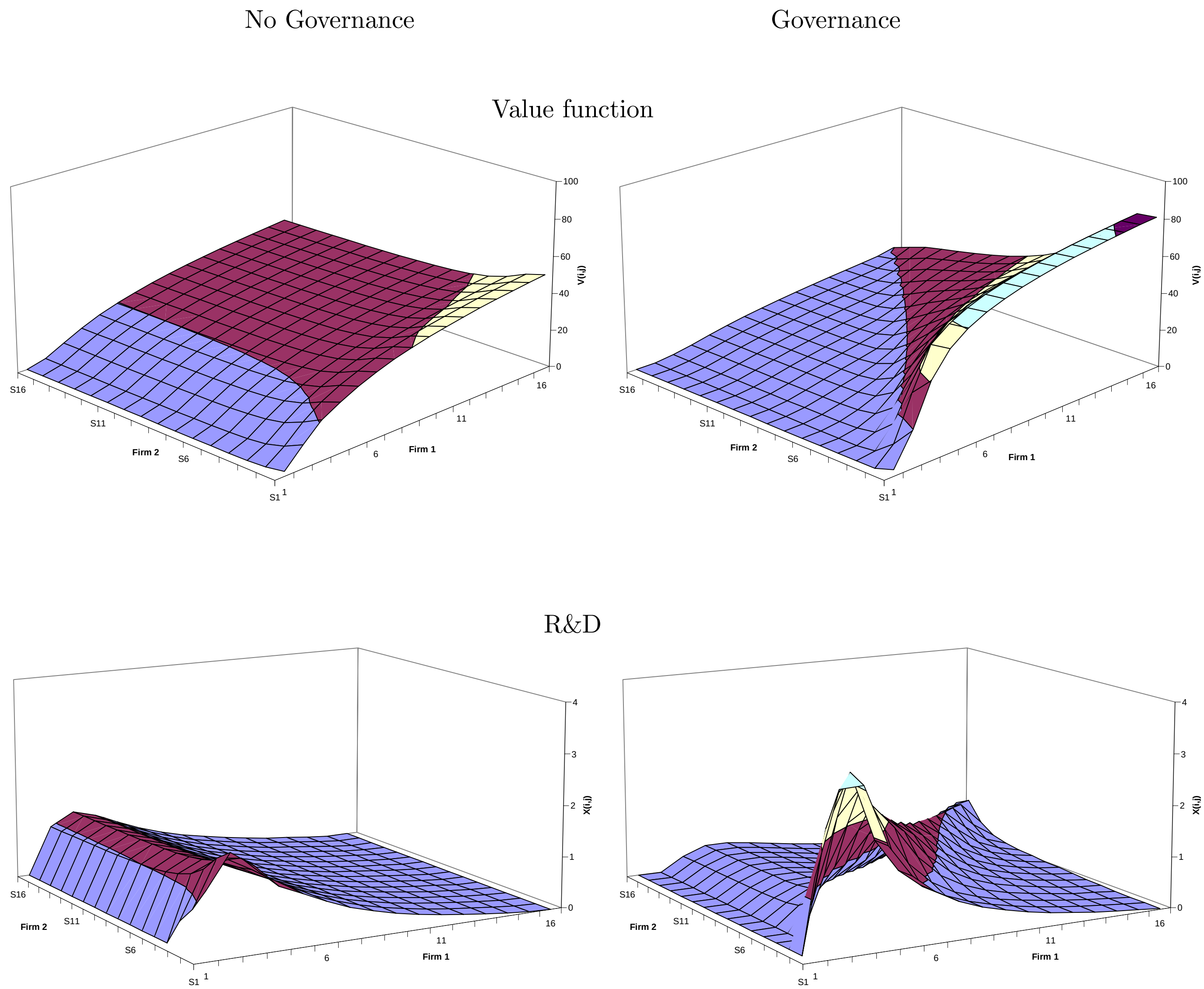


The top two panels plot the probability that Firm 1 decides to enter, $p_1^E\left(\omega_1^E, \omega_2\right)$, as a function of the incumbent Firm 2's state, ω_2. Firm 1 enters in state 2. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

The bottom two panels plot the probability that Firm 1 decides to exit as a function of the state of the industry, (ω_1, ω_2). The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Figure 5: Value Function and R&D

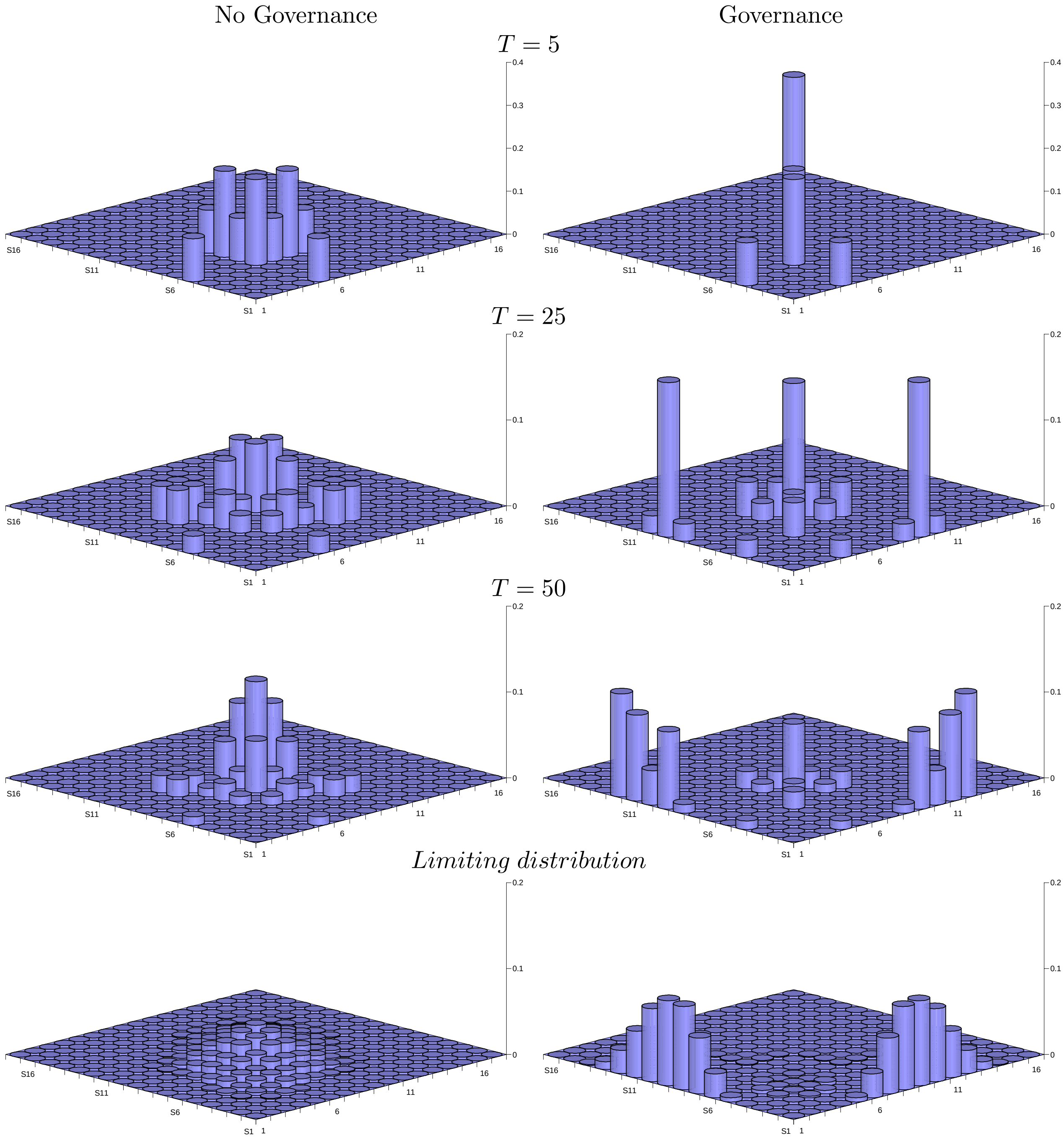


The top two panels plot the value function of Firm 1, $V_1(\omega_1, \omega_2)$, as a function of the state of the industry, $\omega = (\omega_1, \omega_2)$, assuming that two firms are active: Firm 1 and Firm 2. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

The bottom two panels plot R&D expenditure of Firm 1, $x_1(\omega_1, \omega_2)$, as a function of the state of the industry, $\omega = (\omega_1, \omega_2)$, assuming that two firms are active: Firm 1 and Firm 2. The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X_e=0.2, δ=0.5, D=5

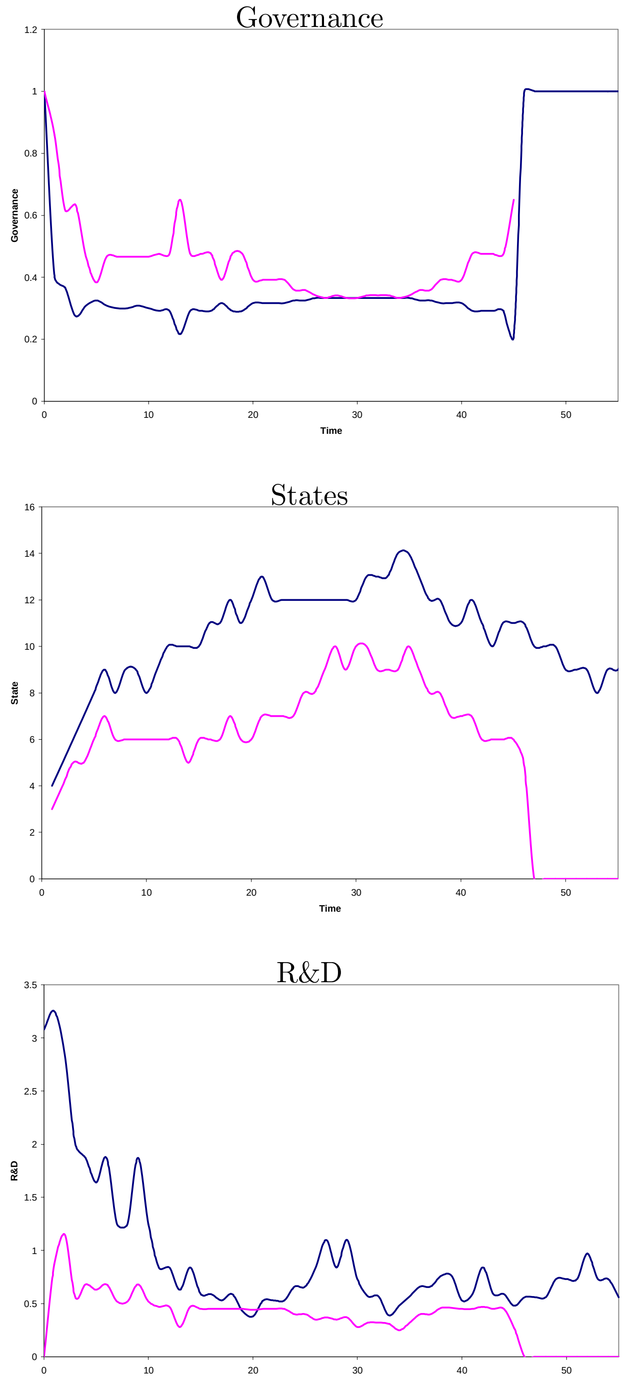
Figure 6: Evolution of market structure



We plot the frequency with which an industry configuration (ω_1, ω_2) occurs after $T = 5, 25, 50$ years and the limiting distribution ($T = 10000$). States $(\cdot, 1)$ and $(1, \cdot)$ correspond to monopolization of the industry by Firm 1 (Firm 2). The two panels correspond to the benchmark model ("No Governance", $\lambda = 0$) and the endogenous governance model ("Governance"). Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X_e=0.2, δ=0.5, D=5

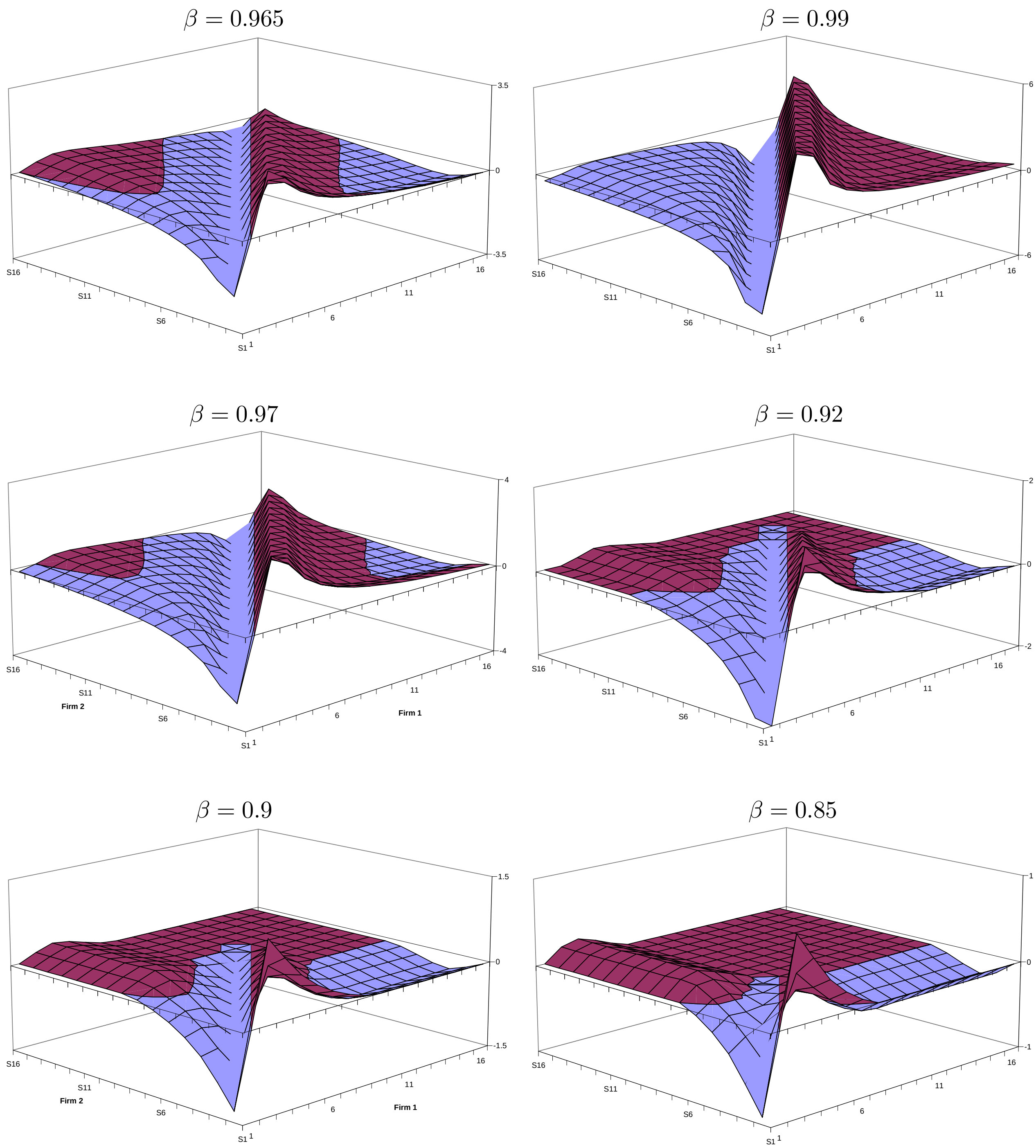
Figure 7: A Governance War



We look at the evolution of two firms' governance, states, and R&D over an episode of a length of 55 years that starts with entry by Firm 2 (dotted line) and ends with that firm exiting. Higher states correspond to lower marginal costs.

Parameter values: β=0.965, ϕ=0.1, X_e=0.2, δ=0.5, D=5

Figure 9: Comparative Dynamics: Increasing Dominance



We plot the difference between R&D activity of Firm 1 and Firm 2, $x(\omega_i - \omega_j) - x(\omega_j - \omega_i)$, as a function of own state and the rival's state, $\omega = (\omega_1, \omega_2)$, for a range of discount factors, β. Higher states correspond to lower marginal costs. Other parameter values: ϕ=0.1, X_e=0.2, δ=0.5, D=5