Silo or Market:

Internal Labor Markets in Multidivisional Firms

PRELIMINARY AND INCOMPLETE

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Abstract

Large corporations are increasingly concerned with assigning their top performers to the most productive positions. In particular, they try to facilitate mobility not only within divisional job ladders ("silos") but across divisions as well. We argue that middle managers play a key role in how internal labor markets operate: they are responsible for mentoring people, and want to hold on to their best performers and get rid of the weakest ones. We develop a model of a firm with two divisions in which managers invest in training their workers, who then may be eligible for promotion to manager of a different division. We show that even in the absence of information problems, a market with cross-divisional transfers leads to a more efficient allocation of employees but comes at the cost of weaker incentives for managers to train their workers. This negative incentive effect is worse when in addition, managers have private information about their workers' ability, and wage contracts must be designed to induce managers to communicate truthfully about their workers. Depending on the parameters, either a "silo" solution or a "market" can be optimal for the firm. We embed our firm model within a model of oligopolistic product market competition, and show that greater product market competition helps explain why the trend for firms to establish cross-divisional internal labor markets is a relatively recent phenomenon.

Keywords: internal labor markets, organizational structure, intra-fiim mobility, careers, training

JEL-codes: D2, D8, L2, M5

1 Introduction

> "Too many companies pay too little attention to allocating their internal talent resources effectively... Many a frustrated manager has searched in vain for the right person for a particular job, knowing that he or she works somewhere in the company. And many talented people have had the experience of getting stuck in a dead-end corner of the company..." (Bryan et al., 2006)

Identifying talented employees has become one of the most important challenges facing modern firms. Large corporations not only look for new ways to recruit employees (Anders 2011), but struggle to identify the right people for positions even within their own ranks (Bryan et al. 2006). Part of the problem is that employees are often perceived to be, and perceive themselves to be, stuck in divisional "silos" with limited upward and no lateral mobility or visibility.[1] More and more corporations are attempting to break up these silos by reorganizing their internal labor markets in many different ways.[2]

In our view, the silo metaphor also captures neatly how economic research has looked at internal labor markets. Building on the pioneering work of Becker (1964) and Doeringer and Piore (1971), economists have delivered many theoretical and empirical insights into the connections between jobs, promotions, human capital acquisition and wages.[3] This literature, however, has focused on "job ladders" that involve, with few exceptions, only vertical mobility. In addition, while learning about employees' abilities plays an important role in many theories, it is usually "the firm" and not individuals that does the learning (for a recent exception, see Kim, 2011).

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[1] "The term 'silo' is a metaphor suggesting a similarity between grain silos that segregate one type of grain from another and the segregated parts of an organization" (Rosen, 2010)

[2] Globally operating multi-divisional corporations like General Electric, Procter and Gamble, Johnson & Johnson, HSBC, or Novartis have been the first to recognize the necessity of programs designed to identify and motivate talent in the various units of the firm. Programs used cover a broad range of instruments such as global evaluation systems, review boards, talent pols and academies (such as GE's leadership course in Crotonville established by Jack Welch). For references, see the respective HBS cases (to be added).

[3] For overviews of the field, see Gibbons and Waldman (1999), Waldman (2011).

Our opening quote suggests that modern firms grapple with problems not addressed by existing economic theories: firms want to be able move employees across divisions and not just vertically, and are limited in their ability to do so because information about employees' abilites is dispersed. These are the problems we address in this paper.

We extend the theory of internal labor markets in two ways. First, we examine the challenges involved in creating an internal labor market with cross-divisional mobility. Within a simple model of a two-divisional firm, we explain how silos emerge endogenously, how firms can design contracts to facilitate cross-divisional transfers, and what the tradeoffs involved are. We link the firm's optimal organization of its internal labor market to its product market environment and its production technology, and argue that some of the forces that have fueled a "War for Talent" (Chambers et al. 1998) among firms in the past decade, including the globalization of markets, are also forces toward reorganization of firms' internal labor markets.

Second, we extend the theory of internal labor markets by highlighting the role that middle managers, or "bosses", play in them, a theme also emphasized in the recent empirical work of Lazear et al. (2011). Managers play a critical role in hiring and mentoring their subordinates; some incentive implications of this role are pointed out in Carmichael (1985) and Friebel and Raith (2004). Managers also prefer to have good employees, and are reluctant to lose good employees to another unit. This preference originates from the team nature of production in firms (Alchian and Demsetz 1972), which makes it impossible to disentangle the contributions of employees in the same unit. Finally, in the course of working with their employees, managers gain information about dimensions of their employees' abilities that is unavailable to others in the firm, in particular to top management or the HR office.

These three features of managerial jobs create incentives to act strategically in supporting or hindering the operation of a firm's internal labor market. As Peter Drucker observed over 50 years ago,

> "Nothing does more harm than the too common practice of promoting a poor man to get rid of him, or of denying a good man promotion 'because we don't know what we'd do without him'. The promotion system must insure

> that everybody who is eligible is considered – and not just the most highly visible people. It must ensure careful review of all promotional decisions by higher management to make difficult alike kicking upstairs and hoarding good people" (Drucker 1954, p.154-155)

Managers' strategic behavior in mentoring their employees and in recommending them to others in the organization is the key element of our theory. To exaggerate our point, the employees in question are reduced in our model to non-strategic pawns in a game between their bosses and top management.

Specifically, we develop a model of a two-divisional firm in which each division manager screens or trains a worker working in her division. When a vacancy arises at the division manager level, the firm would prefer to fill it with a qualified worker, possibly from the other division. The driving force here is that a higher position in the firm's hierarchy is associated with a greater productivity of a manager's ability, in line with many theories of internal labor markets (such as Rosen, 1982, or Qian, 1994) and with evidence (Lazear et al. 2011). However, the firm faces the constraint that the division managers have private information about their workers' abilities, and may prefer to "hoard" a good worker or "kick upstairs" a bad one, as pointed out in the Drucker quote above. For most of our analysis, we assume that managers are risk-neutral and protected by limited liability, and that wage contracts are linear in both divisions' outputs.

With silos, there is no connection between the two divisions, and it is optimal to pay each division manager based on her division's output only. Given division-based incentives, however, managers will not communicate truthfully about their workers' abilities even if asked by the CEO. This means that silos can persist in an organization simply as a result of division-based incentives, even if the CEO wishes to enable cross-divisional transfers by asking managers about their workers.

Implementing an internal "market" in which one division's worker can be promoted to the other division's manager affects managers' incentives to train their workers in several ways.[4] Consider as a benchmark case a firm in which the CEO is perfectly informed

[4] The term "market" belongs in quotation marks because it is not a market with prices but involves top-down exercise of authority. Nevertheless, henceforth, we shall omit the quotation marks.

about workers' abilities. Then the cost to the firm of inducing managerial effort is higher compared with a silo because each manager faces a positive probability of losing a good worker to the other division. On the other hand, the benefit to the firm of inducing managerial effort is higher too, for the same reason: a good worker can, with positive probability, be promoted to a position in which he is more productive. Either effect can dominate; that is, a market with full information may or may not dominate silos.

A market is (much) more difficult to implement when managers have private information about their workers. Aside from the dilutive effect on incentives just discussed, managers with private information must be induced to communicate truthfully, which requires rewarding them in part for outcomes in other divisions, and further raises the costs of inducing effort.

In general, then, there is a tradeoff between assignment efficiency and managerial effort in the optimal organization of an internal labor market. Contrary to the impression created in the popular press that silos are an example of organizational dysfunction, silos provide the best way to incentivize managers to recruit and train the best people. Only when the mobility of employees becomes very important, firms attempt to break up the silos. These attempts, in turn, may explain the apparent decline in mentoring by bosses lamented by Capelli (2011). That is, failing to mentor employees may be a rational response by managers to policies that separate good employees from the managers who trained them.

We embed our organizational model in an oligopolistic market; specifically, each division competes in its market by working to raise product quality or lower production costs. We show that an increase in product market competition raises the value of quality increases or cost reductions, and thereby raises the value to the firm of getting good people to the top of each division. We show that for lower levels of competition, the "silo" solution tends to be optimal because it provides optimal effort incentives in each division, whereas the benefits of diagonal transfers are limited. As competition increases, the initial response of the firm is simply to provide stronger incentives. At some point, however, it becomes optimal for the firm to switch to a market in which cross-divisional transfers occur in equilibrium. This result helps to explain why companies nowadays find themselves in a "war for talent" and look for ways to break down divisional silos, whereas silos were not a hot-button issue in the past.

Our paper contributes to a large theoretical literature on internal labor markets. Gibbons and Waldman (1999) discuss three main recent approaches to explaining multiple stylized empirical facts: Demougin and Siow (1994) focus on slot constraints, and the opportunity cost of training workers to become managers in the firm are the main determinant of the structure of internal labor markets.[5] Informational asymmetries and strategic behavior (absent in Demougin and Siow) play a central role in contributions by Malcolmson and coauthors (most relevant for our paper, Fairburn and Malcomson, 1994) who argue that internal labor markets are used by firms to commit themselves to incentive contracts. In Malcolmson's framework, both principal and agents behave opportunistically. Gibbons and Waldman (1999), finally, abstract from potential commitment problems of firms and focus on worker/job assignments to solve problems resulting from imperfect information and moral hazard. Firms assign workers to jobs, and promotions provide incentives to workers to invest in human capital. Both workers and the firm learn about a worker's type. Of these three approaches, our paper is closest to Gibbons and Waldman, in that as we look at a problem of human capital acquisition under imperfect information. However, training efforts are not carried out by workers, but by managers, and information is not acquired by the firm, but by the same, self-interested, managers. Our focus on managers is not only in line with the reality of of many workplaces, we also show that the private information of managers is crucial for the optimality of silo versus market.

We are not the first to look at the role of managers/evaluators as agents (Malcolmson and Fairburn (1994), Prendergast and Topel (1996), Friebel and Raith (2004), Kim (2011), but our theory is the first to explain different structures of internal labor markets by considering the costs and benefits of revealing provate information about workers, both in terms of worker assignment and human capital investment.

In our theory, internal re-assignment of workers across divisions mutes incentives, and must hence be accompanied with stronger monetary incentives. To the extent that

[5] See Chase (1991) and Pinfield (1995) for a sociological approach, and for empirical work, respectively.

reassignemnt can be seen as similar to poaching in labor markets, this is reminiscent to Waldman (1984) who shows that the risk of other firms' poaching of talented employees leads to distortions in the promotion policies of firms.

Another element of our theory is the tradeoff involved when coordination requires truthful communication which in turn affects incentives which gies back to Levitt and Snyder (1997), and has, in the context of organizational economics, been analyzed by Athey and Roberts (2001), Dessein et al (2010), and Friebel and Raith (2010). related to this tradeoff are models on cheap talk in multi-divisional organizations such as Alonso et al (2008), and Rantakari (2009).

We embed our theory in a product market and thus look at the impact of competition on organizational structure. Theory papers include Grossman and Helpman (2002), Raith (2003), and Alonso et al (2012), and a thriving literature has looked at empirical support for these models, for instance, Cuñat and Guadalupe (2005, 2009), Bloom and Van Reenen (2007), Rajan and Wulf (2006), Guadalupe and Wulf (2010), Giroud and Müller (2010, 2011).

2 Model

Our model consists of a firm with two divisions headed by a CEO (male); see the organizational chart.

Each division $i = A, B$ consists of a manager M_i (female) and a worker W_i (male). Division output is the result of team production and depends on the productivity of the manager and the worker. Managerial effort in our model is directed at hiring and training a good worker; there is no moral hazard in production. Each manager is compensated based on the output of her division (possibly the other division too), which because of team production means that it is in her interest to train and retain a good worker. Each manager leaves the firm with some exogenous probability, creating a vacancy that must be filled from within or outside the firm. A key assumption is that the manager's productivity has a greater weight in the productivity of a manager-worker team, which is why it is in the interest of the firm to fill any vacancy at the managerial level with a good worker if one can be identified.

Wage contracts are designed by the firm; the managers are the main agents in the model. The workers are not players in a game-theoretic sense. The CEO fills vacancies at the managerial level and in doing so maximizes the firm's profit. As we will show, it is irrelevant whether the CEO can commit to a "silo" or "market" policy, or whether he makes promotion decisions that are ex-post optimal for the firm. Initially, we assume commitment is possible, which reduces the CEO's role to executing the firm's internal labor market policy.

Timing:

1. The firm hires M_A and M_B. More precisely, the firm offers each manager a contract whose resulting expected utility weakly exceeds her reservation utility. Each manager has productivity q_m.

2. Each manager M_i $(i = A, B)$ hires a worker W_i and invests effort $e_i \in [0, \overline{e})$ for some upper bound $\overline{e} \leq 1$ in the development of the worker. As a result, the worker is either good (productivity q_g), which occurs with probability e_i, or bad (productivity q_b). The cost of effort is $\psi(e)$ with $\psi', \psi'', \psi''' \geq 0$, and $\psi'(0) = 0$ and $\lim_{e_i \to \overline{e}} \psi'(e_i) = \infty$.

3. M_i learns the type of W_i, which is private information. The idea here is that M_i and W_i work together and thereby get to know each other, see also Friebel and Raith (2004). This assumption is one major departure from most of the the literature on internal labor markets which assumes that "the firm" learns about its workers' abilities.

4. If requested, each manager sends a report about the type of her worker to the CEO.

5. With probability $1 - \sigma$, each manager leaves for exogenous reasons (thus σ is the probability of staying), which leads to changes in the divisional composition of people. What follows are some basic assumptions. From those we derive below some patterns about the CEO's replacement decisions.

    - A departing manager is replaced either with a worker promoted from her own or the other division, or with an outside hire. The feasibility of hiring from outside is parameterized by $\xi \in [0,1]$. If $\xi = 0$, then a manager must be replaced from inside, for instance because of an unmodeled promote-from-within policy or of significant firm-specific human capital that must be acquired by being a worker in the firm first. In this case, a departing manager is, if necessary, replaced by a worker known to be bad. In contrast, if $\xi = 1$, then a new manager can be hired from outside with productivity $q_o \in (q_b, q_g)$. Although our main interest is in the two polar cases $\xi \in \{0, 1\}$, most of our analysis treats ξ as a continuous parameter.

- A good worker promoted to manager within the *same* division is good with probability ϕ. A promoted bad worker is a bad manager with probability 1. We allow for $\phi < 1$ to account for the possibility that even a good worker may not be up to the responsibilities of the job of manager (i.e. may be promoted "beyond his level of competence"), whereas a bad worker will certainly fail to be a good manager.
- A good worker promoted to manager in the *other* division is a good manager with probability $\delta\phi$. The additional discount factor $\delta \leq 1$ allows for human capital to be partly division-specific (which constitutes an intermediate case between firm-specific and task-specific human capital, see Gibbons and Waldman (2004)).
- Any worker who is promoted is replaced by a new worker hired from outside, who has deterministic productivity $q_o \in (q_b, q_g)$.

6. Division i's output is $y_i \in [0, 1]$; its c.d.f. belongs to a family of distributions $F(y; t)$ with parameter $t \in (0, 1)$ such that $E[y] = t$. An example of such a family is the Beta distribution $B(\alpha, \beta)$ with $\alpha > 0$ and $\beta = 1$. In this case, $E(y) = \alpha/(1 + \alpha)$, which means that the value of α corresponding to $E[y] = t$ is $\alpha = t/(1 - t)$.

The parameter t, in turn, is a weighted average of M_i's and W_i's productivities:

$$t = \kappa q_i^m + (1 - \kappa) q_i^w, \tag{1}$$

where $q_i^m \in \{q_m, q_g, q_b, q_o\}$ depending on whether M is the original hire, a good or bad promoted worker, or an outside hire; and where $q_i^w \in \{q_g, q_b, q_o\}$ depending on whether

W is the original hire (first two cases) or hired from outside (last case). This specification means in particular that division output is team production: division i's expected output is linearly increasing in the productivity of both M and W, but it is impossible to infer the type of M or W from realized output. Assume $\kappa \geq 1/2$, which reflects the relatively greater importance of the manager's type for the division's productivity. See the Introduction for a discussion of these two assumptions.

Payoffs and contracts: Managers are risk-neutral and are protected by limited liability; specifically, we assume that compensation must be non-negative. Manager M_i's utility is given by

$$U_i = w_i - \psi(e_i).$$

A manager accepts to work for the firm if his expected equilibrium utility is at least $\underline{U}$. To simplify the analysis, however, we assume that $\underline{U}$ is low enough such that the limited-liability constraint is binding and the participation constraint is not. The firm's payoff for division i is given by

$$\pi_i = Ry_i - w_i.$$

In our analysis, we generally treat R as exogenous. In Section 4, we argue that R is increasing in the degree of product market competition.

Each manager's wage can be made contingent on y_1 and y_2 only. Moreover, we assume for simplicity that feasible wage contracts must be linear in y_1 and y_2; that is, we consider wages of the form

$$w_i = \alpha + \beta y_i + \gamma y_{j \neq i}$$

for symmetric coefficients (α, β, γ) for each manager. There are many other possible contract spaces to consider, such as message-contingent wages or wages contingent on the occurrence of a vacancy or a cross-divisional transfer. We later discuss alternative contract spaces and organizational policies.

Because the firm and the managers are risk-neutral and contracts are constrained to be linear, only the expected value of y_i, as specified by (1), matters for the analysis.

Any manager who leaves for exogenous reasons receives her reservation utility $\underline{U}$. The firm must pay the manager who replaces her, but there is no need for a new manager's wage contract to be the same as the departing one's. For simplicity, we assume that any manager who replaces an original hire in division i receives $\alpha + \beta_r y_i$.

Silo vs. Market: Since each manager stays with the firm with probability σ, four possible cases can arise: both managers stay, M_A stays but M_B leaves, M_B stays but M_A leaves, or both managers leave. We distinguish two ways to organize an internal labor market that replaces departing managers.

With "silos", a departing manager must be replaced by her "own" worker, i.e. the worker from the same division (who is in turn replaced by an outside hire) or from outside. With a "market", a departing manager can also be replaced by the worker in the other division. Because human capital is weakly division-specific ($\delta \leq 1$), promoting the own worker is optimal if both workers have the same ability. However, if (say) M_B leaves, then promoting W_A to manager of division B can be beneficial to the firm if W_A is good *and* W_B is bad *and* M_A does not leave as well (if she did, it would be weakly optimal to promote a good W_A within the same division). The alternative in this case would be to hire from outside (if feasible). For cross-divisional promotions to be relevant, it is necessary that the expected productivity of promoting a good worker from the other division is higher than the productivity of an outside hire:

$$\delta\phi q_g + (1 - \delta\phi)q_b > q_o.$$

On the other hand, if in equilibrium a manager invests high effort and thus has a good worker with high probability, then the CEO might prefer to promote a worker instead of hiring from outside just based on ex-ante expectations, i.e. without knowing the worker's type. Not requiring a manager's private information would relax truthtelling incentive constraints and thus save on wage costs, but would also lead to suboptimal promotion decisions. Since this complication adds no economic insight to the problem of interest, we assume that the ex-ante expected equilibrium productivity of a promoted worker is lower than the productivity of an outside hire. Since $\bar{e}$ is an upper bound to effort, a sufficient condition is

$$\bar{e}[\phi q_g + (1 - \phi)q_b] + (1 - \bar{e})q_b < q_o.$$

Note that the only turnover in our model is generated by manager departures. A bad worker is not fired even after his manager has learned his type. This assumption can be motivated by turnover costs: any *vacancy* at the manager or worker level must be filled either by promoting a worker or by hiring a manager or worker from outside, but *replacing* people because they are below average is prohibitively costly. Enriching the model to allow for replacement of bad workers would reduce managers' incentives to misrepresent a bad worker as a good one. As we will see, however, when outside hires at the manager level are allowed, this incentive is not binding anyway.

The decision on which worker to promote (which can arise only when exactly one manager leaves) depends on the CEO's information about the workers' abilities. Below, we will consider a benchmark case in which the CEO has perfect information, and therefore always makes ex-post optimal decisions for the firm. Our main case of interest, however, is the situation in which managers have private information about their workers' abilities. We assume that at the departure of manager M_i, the CEO asks both the departing and the remaining manager to report their workers' types. As we will see, it does not matter whether these reports are verifiable or cheap talk. The departing manager M_i truthfully reveals information about W_i because there is nothing at stake for her in communicating her worker's type. The remaining manager M_j will report W_j's type truthfully only if it is in her best interest, which it may not be because she might have an incentive to "hoard" a good worker or "kick upstairs" a bad one. Wage contracts must therefore be designed to induce truthtelling; we formulate the relevant truthtelling conditions further below when we study the case of private information.

3 Analysis

In this section, we characterize optimal wage contracts for three different cases. The first case is silos. Second, we consider the benchmark case of a market with cross-divisional promotions in which the CEO has perfect information about workers' abilities. The third case is that of a market in which only the managers know their own worker's productivity, which requires wage contracts to be designed to induce truthtelling. We then compare the choice between silo and market in Section 4.

3.1 Silo

We begin by constructing the firm's and a manager's payoffs. In accordance with (1), denote the productivity of a team consisting of a manager of productivity q_x and worker q_y by $t_{xy} = \kappa q_x + (1-\kappa)q_y$, where $x, y \in \{m, g, b, o\}$. Denote by $t_0(e)$ the productivity of the original manager-worker team. This team remains in place if the manager stays with the firm. Its productivity depends on the manager's effort e, which results in having either a good or a bad worker:

$$t_0(e) = et_{mg} + (1-e)t_{mb} = \kappa q_m + (1-\kappa)[eq_g + (1-e)q_b].$$

Suppose, instead, the manager leaves and must be replaced (hence the index 'r' in the equation below). If the manager has a good worker (with probability e), the worker is promoted to manager but is a good manager only with probability ϕ. A new worker is hired from outside. If the worker is bad (probability $1-e$), then the manager's position is filled from outside if feasible ($\xi = 1$) while the worker stays in his position. If outside hiring is infeasible, the worker is promoted, a new one is hired from outside. The resulting expected output of the division is then given by

$$t_r(e) = e[\phi t_{go} + (1-\phi)t_{bo}] + (1-e)[\xi t_{ob} + (1-\xi)t_{bo}].$$

With silos, manager M_i has no influence over the productivity of division $j \neq i$. There is therefore no benefit of paying M_i a bonus γ based on y_j; set $\gamma = 0$. The contracting problem then reduces to a simple single-agent problem. The firm's expected profit from division A is a weighted average of the profit for the cases in which M_A stays or leaves, respectively:

$$\sigma t_0(e_A)(R-\beta) + (1-\sigma)t_r(e_A)(R-\beta_r)$$

M_A's payoff is a similar weighted average:

$$V_A^S = \sigma t_0(e_A)\beta + (1-\sigma)\overline{U} - \psi(e_A)$$

The firm's contracting problem then is

$$\begin{aligned} &\max_{\beta,e} \sigma t_0(e)(R-\beta) + (1-\sigma)t_r(e)(R-\beta_r) \\ \text{s.t. } e \;&=\; \arg\max_{e'} \sigma t_0(e')\beta + (1-\sigma)\overline{U} - \psi(e') \end{aligned}$$

Proposition 1 *With silos, each manager's optimal effort e satisfies*

$$\sigma(1-\kappa)(q_g - q_b)\beta = \psi'(e).$$

The optimal contract is characterized by $\beta > o$ and $\gamma = 0$. The firm's equilibrium profit is increasing in R, ϕ, and ξ, and increasing or decreasing in κ and σ. Both the optimal value of β and the equilibrium level of e are increasing in R, increasing in ϕ, decreasing in ξ, and increasing or decreasing in κ and σ.

It is straightforward that profit, β and e are all increasing in R, the value of output. It is also clear that profit is increasing in both ϕ and ξ; in the case of ϕ because it means a promoted worker is more likely to be a good manager, and in the case of ξ because of a better chance of replacing a manager with an outsider rather than a bad worker. The two parameters have opposite effects on β and e, however: a higher option value of a worker also implies a higher value of effort (β and e increasing in ϕ), whereas a more "porous" labor market at the top reduces the value of a having a good worker (β and e decreasing in ξ).

The dependence of profit, β and e on κ and σ is indeterminate partly because the direct effect on profit alone is already indeterminate, i.e. even ignoring the effort incentive constraint. For instance, a higher value of κ means that the worker is less important to the firm if the manager stays, but potentially more important if the manager leaves and the worker might be promoted. Even though intuition suggests that as long as the probability that the manager stays is large enough, profit and effort should both be decreasing in σ, but there is no simple condition that expresses when this intuition would be correct. The dependence of β on κ and σ is ambiguous in addition because these parameters tend to have opposite effects on profits and effort incentives. For example, even if a higher value of κ means that having a good worker is less important to the firm, κ also has a direct negative effect on the manager's effort, because a good worker is less important for the manager too; see (1). To counteract the resulting lower marginal benefit of effort, the firm would want to raise β. Which of these effects dominates is ambiguous.

3.2 Market with full information

To gain insight into how a market with cross-divisional promotions differs from silos, we first study the case of a market in which the CEO is perfectly informed about both workers' abilities; that is, where the managers do not possess any private information about their workers.

Whether the internal labor market is a silo or market makes a difference only if exactly one manager leaves (if both leave, each manager is replaced from within the division or from outside, just like in the silo case). Even then, having a market instead of silos matters only if the departing manager's worker is bad and the other division's worker is good, for otherwise the departing manager is replaced in the same fashion as with silos.

To construct the firm's and the managers' payoff functions, we begin with some notation. Denote by $y_i(s_A, s_B)$ the expected output of division i (as of the beginning of stage 5 of the timing described in Section 2) for the case in which $s_i = 1$ if M_i stays and $s_i = 0$ if M_i leaves. There is an abuse of notation here in that all expected outputs $y_i(s_A, s_B)$ are functions of e_A and e_B as well. The payoffs are given in the following table and explained below.

$$
\begin{array}{rlrl}
y_A(1,1) = & t_0(e_A), & y_B(1,1) = & t_0(e_B), \\
y_A(1,0) = & e_A e_B t_{mg} & y_B(1,0) = & e_B[\phi t_{go}(1-\phi)t_{bo}] \\
& +e_A(1-e_B)t_{mo} + (1-e_A)t_{mb}, & & +(1-e_B)\{e_A[\delta\phi t_{gb} + (1-\delta\phi)q_b] \\
& & & +(1-e_A)[\xi t_{ob} + (1-\xi)t_{bo}]\}, \\
y_A(0,1) = & e_A[\phi t_{go}(1-\phi)t_{bo}] & y_A(0,1) = & e_A e_B t_{mg} \\
& +(1-e_A)\{e_B[\delta\phi t_{gb} + (1-\delta\phi)q_b] & & +e_B(1-e_A)t_{mo} + (1-e_B)t_{mb}, \\
& +(1-e_B)[\xi t_{ob} + (1-\xi)t_{bo}]\}, & & \\
y_A(0,0) = & t_r(e_A), & y_B(0,0) = & t_r(e_B).
\end{array}
$$

If both managers stay, the original teams remain in place in each division, and the expected output is $t_0(e_i)$ as explained in Section 3.1. Likewise, if both managers leave (last row in (3.2)), then they are replaced either by their worker or from outside as discussed in Section 3.1, and the expected output is $t_r(e_i)$.

If M_B leaves while M_A stays, then there are three possible team compositions in division A: if both workers are good, W_B is promoted to M_B, and in division A the original team (with productivity t_{mg}) stays intact. Likewise, if W_A is bad, there is no change in division A (productivity t_{mb}). If, however, W_B is bad and W_A good, then W_A is promoted to M_B and a new worker hired in division A, resulting in a team with productivity t_{mo}. In division B, there are three possible team compositions as well: a good W_B is promoted (first term of $y_B(1,0)$). If W_B is bad, then if W_A is good he is promoted to M_B (first term inside $\{\}$-brackets); otherwise M_B is replaced either from outside or with a bad W_B (second term inside $\{\}$-brackets). The case where M_A leaves and M_B stays is analogous.

At stage 2 of the game (effort choice), Manager M_A's expected payoff is then given by

$$V_A^M(e_A, e_B) = \sigma^2[\beta y_A(1,1)+\gamma y_B(1,1)]+\sigma(1-\sigma)[\beta y_A(1,0)+\gamma y_B(1,0)]+(1-\sigma)\underline{U}-\psi(e_A),$$

and M_B's payoff is defined analogously. We can exploit the symmetry of the model to simplify the firm's contracting problem, by determining the contract that maximizes the profit from *one* division. Making this step requires determining whether, for instance, M_A's bonus γy_B should be subtracted from the profit of division A or of division B; both are possible choices. Let us therefore define division A's profit as the revenue from output in division A (Ry_A), minus the total compensation paid to M_A or her replacement:

$$\begin{aligned}\pi_A^M(e_A, e_B) &= \sigma^2[(R-\beta)y_A(1,1)-\gamma y_B(1,1)]+\sigma(1-\sigma)[(R-\beta)y_A(1,0)-\gamma y_B(1,0)] \\ &\quad +(1-\sigma)(R-\beta_r)[\sigma y_A(0,1)+(1-\sigma)y_A(0,1)].\end{aligned}$$

Thus, π_A^M includes payments γy_B to M_A, as well as payments $\beta_r y_A$ to M_A were she to leave, but does not include γy_A to M_B.

Given the model's symmetry, the firm's contracting problem is (suppressing arguments)

$$\begin{aligned} &\max_{\beta,\gamma e_A,e_B} \pi_A^M(e_A, e_B) \\ \text{s.t. } e_A &= \arg\max_{e'} V_A^M(e', e_B) \text{ and } e_B = \arg\max_{e'} V_B^M(e_A, e')\end{aligned}$$

Proposition 2 *In a market with full information, it is optimal to set $\beta > 0$ and $\gamma = 0$. There exists a unique, symmetric Nash equilibrium with $e_A = e_B = e$, which satisfies*

$$\{\sigma^2(1-\kappa)(q_g-q_b)+\sigma(1-\sigma)(1-\kappa)[eq_g+(1-e)q_o-q_b]\}\beta = \psi'(e).$$

Both the optimal value of β and the equilibrium level of e are increasing in R, increasing in ϕ and δ, and decreasing in ξ. The firm's equilibrium profit is increasing in all four of these parameters.

First, observe that with a market, each manager's effort depends on the other's; we are thus looking for a Nash equilibrium in (e_A, e_B). With a symmetric model and symmetric wage contracts, the proof of the proposition first shows that for any contract (β, γ), a symmetric Nash equilibrium exists with $e_A = e_B = e$. Given this result, the problem can then be reduced to a single-division problem like in the silo case, only with the profit function $\pi_A^M(e, e)$ and the first-order condition (2), and with a to-be-determined value of $e = e_A = e_B$.

With silos, it is optimal to set $\gamma = 0$ because there is no connection between the divisions. With a market with full information about workers, M_A's effort affects the other division's output y_B because a good W_A is promoted to M_B with positive probability. Nevertheless, it is optimal to set $\gamma = 0$ because the incentives provided through γ are poor: intuitively, incentivizing managerial effort by rewarding a manager based on her own division's performance is cheaper than incentivizing effort by paying for the other division's performance.

Provided that the firm stands to gain from cross-divisional promotions (see (2)), it is clear that any given level of managerial effort is *more valuable* (in terms of revenue, not including wage costs) with a market than with silos. Condition (2) now states that any given level of managerial effort is also *more costly* to induce: if M_B were to stay for sure ($\sigma = 1$), M_A's incentives would be the same as in the silo case (compare (1) with the first term in (2)). However, if M_B were to leave, then M_A would lose her worker to division B with probability $1 - e$ (the probability that M_B has a bad worker) and would have to hire a replacement worker with productivity $q_o < q_g$.

Given $\gamma = 0$, the managers' effort levels are strategic complements: the higher M_B's effort, the more likely a vacancy created by the departure of M_B is filled by W_B. This in turn means that M_A is less likely to lose a good worker to the other division, which increases M_A's incentive to invest effort.

The intuition for the dependence of β and e on R, ϕ, and ξ is the same as in the silo case. A new relevant parameter in the market is δ, the discount factor measuring the division specificity of human capital. Like with ϕ, a higher δ implies a higher value of cross-divisional promotions, and therefore a higher option value for the firm of having good workers.

Observation: The firm's profit with a market can be higher or lower than with silos. The manager's equilibrium effort levels under an optimal contract can be higher or lower with a market than with silos as well. All four different combinations of rankings of profits and equilibrium effort levels can occur, depending on the parameters of the model. The reason for this ambiguity is that with a market, effort directed at training workers is both more valuable for the firm, and is more costly to induce, as discussed above.

Intuitively, the option of promoting a good worker to manager in the other division both raises the value of good workers to the firm, and reduces a manager's incentives to a train good worker because she now stands to lose him. Which effect dominates depends on the parameters of the model, in particular on the disutility of effort $\psi(e)$.

It is useful to interpret Proposition 2 in the context of Williamson's (1985) selective-intervention puzzle. Even without any other synergies between divisions A and B (and ignoring information problems for now), the selective transfer of employees between divisions is a form of value-increasing "selective intervention."[6] However, in line with Williamson's general reasoning, intervention comes at the cost of diluting managers' incentives. Here, the dilution occurs in particularly simple form, because transfering a good worker away from a manager amounts to directly taxing the manager for her effort. Here, as in general, the gain from intervention may or may not exceed the loss due to diluted incentives.

How this tradeoff plays out depends both on the kind of of game managers are involved in, and on contracting constraints. In Friebel and Raith (2010), there are fixed but scarce corporate resources. If the CEO is perfectly informed about the best use of resources in the divsions, competition among managers for resources actually leads to stronger effort incentives than would prevail in stand-alone divisions.

Here, a quite different effect is present although the models may look similar at first

[6] General Electric is a good example of a conglomerate held together significantly by synergies resulting form an actively managed corporate internal labor market; see Linebaugh (2012).

glance: a manager's effort is directed at *creating* a valuable resource (a good worker). The prospect of losing the worker to another division unambiguously decreases effort incentives. Instead of a positive *competition effect* on managerial incentives like in Friebel and Raith (2010), here we have an expropriation effect that unambiguously weakens incentives.

The set of feasible contracts matters too. For instance, if output is binary ($y \in \{0, 1\}$) and wages can be any general function of realizations of (y_A, y_B), then a market with a perfectly informed CEO is more likely to dominates silos. Optimal contracts take the form of a large wage payment if and only if $y_A = y_B = 1$, and a zero wage otherwise. The historic prevalence of siloed internal labor markets in real-world businesses suggests that contracts of this form tend to be infeasible, or may be suboptimal because of managerial risk aversion.

Like in Friebel and Raith (2010), however, the most important source of dilution of managerial incentives is that the CEO is uninformed, and that managers must be induced to communicate truthfully to the CEO. We now turn to this case.

3.3 Market with private information

We now turn to the market in which only M_i knows the productivity of W_i. In this case, the CEO can fill a vacant M_B position optimally only if M_A (assuming she stays) reports the type of her worker truthfully. Manager M_A's report matters only if M_B happens to have a bad worker. Manager M_A of course does not know W_B, but irrelevant events simply cancel out on both sides of the manager's truthtelling constraint. We can therefore focus on the case where W_B is bad.

If M_A has a *good* worker, she will report the worker's type truthfully if

$$\text{(TTg)} \quad \beta t_{mo} + \gamma[\delta\phi t_{gb} + (1 - \delta\phi)q_b] > \beta t_{mg} + \gamma[\xi t_{ob} + (1 - \xi)t_{bo}].$$

The left-hand side of (TTg) is M_A's expected payoff if a good W_A is promoted to M_B. It consists of β times the productivity t_{mo} of a team consisting of the original manager and a new worker; plus γ times the productivity of a team in division B which consists of a good manager and a bad worker if the promoted W_A turns out to be a good M_B

(probability $\delta\phi$), or a bad manager and a bad worker (with team productivity $t_{bb} = q_b$) otherwise. The right-hand side of (TTg) is M_A's expexted wage if she reports her good worker to be bad and holds on to her worker, in which case the productivity of division A is t_{mg}, whereas in division B either a new M_B is hired (while a bad worker remains), which occurs with probability ξ, or W_B is promoted to M_B and a new worker is hired. Condition (TTg) requires γ to be a minimal fraction of β:

$$\gamma_g = \frac{t_{mg} - t_{mo}}{\delta\phi t_{gb} + (1-\delta\phi)q_b - \xi t_{ob} - (1-\xi)t_{bo}}\beta$$

If M_A has a *bad* worker, she will report the worker's type truthfully if

$$\text{(TTb)} \quad \beta t_{mb} + \gamma[\xi t_{ob} + (1-\xi)t_{bo}] > \beta t_{mo} + \gamma q_b.$$

The left-hand side of (TTb) is M_A's expected wage from keeping her bad worker ($E[y_A] = t_{mb}$), while in division B either a new M_B is hired (with probability ξ), or W_B is promoted to M_B. If, on the other hand, M_A reports her worker W_A to be good, then W_A is promoted to M_B, in which case a new worker is hired in division A (resulting in team productivity t_{mo} there), while in division B both manager and worker are bad. Condition (TTb), too, requires γ to be a minimal fraction of β:

$$\gamma_b = \frac{t_{mo} - t_{mb}}{\xi t_{ob} + (1-\xi)t_{bo} - q_b}\beta = \frac{1-\kappa}{1-\kappa+(2\kappa-1)\xi}\beta$$

If $\xi = 1$, then $\gamma \geq \gamma_b = \frac{1-\kappa}{\kappa}\beta$, whereas if $\xi = 0$, then $\gamma \geq \gamma_b = \beta$.

Observation: Both (TTG) and (TTb) are violated if $\gamma = 0$.

This observation is mathematically trivial but economically significant. It shows that the "silo syndrome" plaguing many companies does not require an explicit silo *policy.* Silo *incentives*, instead, are sufficient to undermine a cross-divisional internal labor market. That is, even if the CEO asked the managers about their workers' abilities with an intention of possibly reallocating people across divisions, the managers would misrepresent their information if their incentives are based on their own division's performance only.

In standard adverse-selection problems with one dimension of private information, agents' incentives to lie are unidirectional (e.g. bad types may want to imitate good types but not vice versa). Here, the incentives to lie go in both directions. Nevertheless, with linear contracts, both truthtelling constraints lead to a lower bound for γ as fraction of β: as long as a manager's stake in the other division is large enough, both constraints can be satisfied. Which of the two constraints is the more restrictive one depends on whether hiring managers from outside is feasible:

Lemma 1 *If outside hires are feasible ($\xi = 1$), then (TTg) is more restrictive than (TTb). If outside hires are infeasible ($\xi = 0$), then (TTb) is more restrictive than (TTg).*

As mentioned above, if $\xi = 0$, then $\gamma_b = \beta$, while $\gamma_g < \beta$.

Proposition 3 *In a market with private information, it is optimal to set $\beta > 0$ and $\gamma = \min\{\gamma_g, \gamma_b\}\beta$. There exists a unique, symmetric Nash equilibrium with $e_A = e_B = e$. If $\gamma_g \geq \gamma_b$, and $\gamma = \gamma_g\beta$, then the equilibrium value of e satisfies*

$$\sigma(1-\kappa)(q_g - q_b)\beta = \psi'(e),$$

which is the same condition as (1). Define $\kappa\xi + (1-\kappa)(1-\xi)$. If $\gamma_g < \gamma_b$, which is the case if

$$\tau < \delta\kappa\phi,$$

then then the equilibrium value of e satisfies

(fill in foc)

The equilibrium profit is increasing in R, ϕ, δ and ξ. (CONJECTURE:) Both the optimal value of β and the equilibrium level of e are increasing in R, increasing in ϕ and δ, and decreasing in ξ.

4 Silo or Market?

Depending on the parameters of the model, either silos or a market can be optimal for the firm. The general tradeoff is clear: a market with cross-divisional transfers leads to a more efficient assignment of employees, but establishing truthful communication by managers about their workers raises the costs of inducing effort. In this section, we examine how the choice between silos and market depends on different parameters. We begin with a simple market model that suggests a link between the value of output R and the degree of product market competition, and then proceed to examine the choice between silo and market.

4.1 Product market competition and the value of output

This subsection argues that if the firm's production (resulting in outputs y_i) is directed at increasing its competitive position in the market, either by reducing costs or by raising demand, then greater product market competition will be associated with a higher value of R.The general idea is the same as in Raith (2003), see also Vives (2008) for a related theoretical discussion and Bloom and Van Reenen (2007) for empirical evidence. Readers familiar with it can without loss proceed to Section 4.2.

Suppose each division of the firm operates in an oligopolistic market in which it competes with $n-1$ divisions of identical multi-product firms. Suppose further that for firm k, inverse demand is given by

$$p_k = a_k - \frac{1}{m}q_k - \frac{\gamma}{m}\sum_{l \neq k} q_l,$$

where $a_k = a + \Delta y_k$, where y_k is the output of one of firm k's divisions, and $\Delta \geq 0$ is a scaling parameter. Firm k has constant marginal cost c, and its profit is thus given by

$$\pi_k = (p_k - c)q_k.$$

Each firm k chooses q_k after observing the realization of $a_k = a + \Delta y_k$ but without knowing the other firms' realizations of y_l for $l \neq k$. The value of y to the firm can be expressed as Ry, where

$$R = E[\pi_k \mid y_k = 1] - E[\pi_k \mid y_k = 0]. \tag{2}$$

Firms incur fixed costs of F to operate in the market. We assume free entry; that is, the number of firms n is determined by a zero profit condition $\pi_k = F$. The timing of the game is thus: 1. Firms enter the market; 2. Division output y_k is realized for each firm k and is known only to firm k; 3. each firm k chooses output q_k.

Although the product market is modeled as a Cournot market here, it does not matter for our results whether firms compete in quantities or prices. It also does not matter whether divisional output "y" affects demand or costs. All that matters is that y determines the firm's competitive position in the market relative to other firms. (In Raith (2003), in contrast to the model introduced here, firms invest in cost reductions and compete in prices; the results are nevertheless very similar). We can then show:

Proposition 4 *With an endogenous number of firms n, an increase in market size m or increase in product substitutability γ leads to an increase in R.*

4.2 The choice between silos and market

Our next result, in conjunction with Proposition 4, suggests a link between product market competition and firms' organization of internal labor markets:

Proposition 5 *(/Conjecture) There exists $\tilde{R}$ such that a market with private information is preferred over silos for any $R \geq \tilde{R}$.*

Proposition 5 shows that while silos may be optimal for the firm for smaller values of R, a market is optimal if R is sufficiently large. The strategy of the proof is as follows. For both market and silos, by the envelope theorem, the derivative of the equilibrium profit with respect to R is equal to the partial derivative of the Lagrangian, which in turn is equal to the partial derivative of the profit function because R does not appear in the incentive constraint. For the same level of effort, this partial derivative is strictly greater for the market than for silos. Now, for any set of parameters, the equilibrium levels of effort are of course different for market and silos. However, as R grows without bound, the equilibrium effort increases too, but is bounded by $\bar{e}$. Thus, for both cases the equilibrium effort levels converge to $\bar{e}$, while all other parameters in the derivatives of the profit functions remains unchanged. It follows that eventually the market profit must exceed the silo profit.

In conjunction with Proposition 4, this result suggests that greater product market competition may be one of the forces driving firms' efforts to break up silos and establish cross-divisional mobility of their employees. Notice that there is no assumption here that competition changes the production technology or the relative importance of manager vs. worker. However, the *difference* in the value of having a good employee in the position of a manager or worker (vs. an outside hire as alternative) is proportional to $R(2\kappa - 1)(q_g - q_o)$.Intuitively, if employees in higher positions are more important, then greater competition not only increases the value of having good employees in general, but increases the value of moving the best people to the top.

(Comparative statics with respect to other parameters of the model to be added).

4.3 Contract space, and alternative instruments

We have built the model with risk-neutral managers and linear contracts. The contract space could be enhanced, a problem that awaits systematic treatment. In what follows we discuss some of the issues involved. This discussion is preliminary.

Non-linear contracts make is easier to implement a market; that is, they enlarge the set of parameters for which a market dominates silos. In particular, such a contract stipulates payments to be positive only when both divisions have high output. If this is the case, the payment can be made large enough to provide both strong effort incentives and to satisfy the truth-telling constraint. This type of contract is however not very realistic, because managers' liquidity needs would not be satisfied. A contract of this type also exposes the manager to risks related to the type of the manager and worker in the other division, which would make a difference when risk-aversion of managers would be considered.

One could imagine, though, to make contracts contingent on other things than the performance of the two divisions. First, a bonus can be paid contingent on the export of a worker. Rewarding the export of any worker does not solve any problem, because it even creates an additional adverse incentive to kick up bad workers, and does not reduce the incentive to hoard good workers. Unless the type of an agent can be made verifiable, for instance by some message-contingent contracts and communication with the worker, the bonus can only be made contingent on the increase of division performance because of the transfer of talent. This, however, is subject to a substantial identification problem, as an increase or decrease in division performance can be hardly attributed to the transfer of one person (a variation of Alchian and Demsetz, 1972). Relative performance evaluation, which is tantamount to a difference-in-difference performance evaluation is not manipulation-proof as it may provide perverse incentives for the sending division.

Firms can design other instruments to deal with the problem of kicking up bad and hoarding good people, and the incentive issues for managers subjected to reassignement of the workers they trained. A first, albeit imperfect, but widely used option is to define a certain period of time in which workers can only change jobs when their direct supervisor supports the reassignment. This is a practice that is widely used in firms employing internal labor market practice such as large manufacturers. A second practice, somehow in conflict with the first, is to make workers rotate across divisions and functions, such that the information about the workers' type diffuses more widely within the firm. However, rotation entails the potentially large and disruptive costs of a suboptimal development of task- or division-specific human capital. Ultimately, managers' have insufficient expertise in the divisions they run (Linebaugh 2012), which has led GE to change some of its famous internal labor market practices aimed at making people rotate at high frequency.[7]

Many firms include HR development as a part of the periodic performance evaluation of managers, as a part of the individual objectives agreed upon between managers and their supervisors. However, it is notoriously difficult to find a good metric of evaluating HR development, unless a functioning 360 degree evaluation system is in place, and the results of the evaluation are communicated to the hierarchy (which is usually not the case, for the reasons highlighted by Friebel and Raith, 2004). Firms can try to evaluate inputs, rather than outputs, but this evokes the problems analyzed by papers on specific knowledge (Baker, 1992, Raith, 2008), in particular, it still does not solce the problem of asymmetric information about workers' types.

[7] For a by now classical description about the effects of cross-firm rotation of the french engineering elite from the Ecole polytechnique, see Crozier (1964).

5 Concluding Remarks

Training people, and placing them in the right positions, are fundamental HR challenges of large corporations. Our paper shows that the two problems are necessarily related when part or all of the training costs are borne by the direct supervisors. Because intra-firm assignment remove a worker from the purview of the division manager responsible for training and mentoring, incentives to invest in the worker are muted. In particular, when information about the workers is dispersed, as it seems to be the case in most large corporations, then "silos" in which people do not leave the unit in which they were trained are a likely outcome. Our analysis suggests that the historic prevalance of silos may not be simply a manifestation of organizational dysfunction, but a more or less conscious choice of firms who do not want to undermine the incentives of their managers to train their workers. The recent shift in corporations' policies, and the attention paid by practitioners and consultants to facilitating the firm-wide internal mobility of people, in turn, may have been caused by an increase in product market competition brought about by globalization.

6 Appendix: Proofs

Sketch of Proof of Proposition 1: The Lagrangian of the problem is

$$L(\beta, e, \lambda) = \sigma t_0(e)(R - \beta) + (1 - \sigma)t_r(e)(R - \beta_r) + \lambda[\sigma t_0' \beta - \psi'(e)]$$

for $t_0' := t_0'(e) = (1 - \kappa)(q_g - q_b) > 0$. Also define

$$t_r' := t_r'(e) = \phi t_{go} + (1 - \phi)t_{bo} - \xi t_{ob} - (1 - \xi)t_{bo},$$

which is positive too because the first two terms add up to at least q_o because of (2), and the last two terms add up (in absolute value) to at most $t_{ob} < q_o$. The first-order conditions for the optimal solution are given by

$$\begin{aligned} L_\lambda &= \sigma t_0' \beta - \psi'(e) = 0, \\ L_\beta &= -\sigma t_0(e) + \lambda \sigma t_0' = 0, \\ L_e &= \sigma t_0'(R - \beta) + (1 - \sigma)t_r'(R - \beta_r) - \lambda \psi''(e) = 0. \end{aligned}$$

The Jacobian of this system of equations is

$$M = \begin{pmatrix} 0 & \sigma t_0' & -\psi''(e) \\ \sigma t_0' & 0 & -\sigma t_0' \\ -\psi''(e) & -\sigma t_0' & -\lambda\psi'''(e) \end{pmatrix},$$

which given $\psi'''(e) \geq 0$ is negative semi-definite, and in particular $|M| > 0$. The partial derivatives of $(L_\lambda, L_\beta, L_e)$ with respect to $R, \kappa, \sigma, \phi, \xi$ are given by the following table:

$L_{\lambda R} = 0$	$L_{\beta R} = 0$	$L_{eR} = \sigma t_0' + (1-\sigma)t_r'$
$L_{\lambda\kappa} = -\sigma(q_g - q_b)\beta$	$L_{\beta\kappa} = -\frac{\sigma q_m}{1-\kappa}$	$L_{e\kappa} = -\sigma(q_g - q_b)(R-\beta) + (1-\sigma)\frac{\partial t_r'}{\partial\kappa}(R-\beta_r)$
$L_{\lambda\sigma} = t_0'\beta$	$L_{\beta\sigma} = -t_0(e) + \lambda t_0' = 0$	$L_{e\sigma} = t_0'(R-\beta) - t_r'(R-\beta_r)$
$L_{\lambda\phi} = 0$	$L_{\beta\phi} = 0$	$L_{e\phi} = (1-\sigma)\kappa(q_g - q_b)(R-\beta_r)$
$L_{\lambda\xi} = 0$	$L_{\beta\xi} = 0$	$L_{e\xi} = -(1-\sigma)(2\kappa-1)(q_o - q_b)(R-\beta_r)$

The expressions in the table are straightforward, except for $L_{\beta\kappa} = -\sigma[q_m - eq_g - (1-e)q_b] + \lambda\sigma(q_g - q_b)$, which reduces to the expression stated in the table by using $L_\beta = 0$ to eliminate λ. The comparative-statics results for β and e stated in the proposition are then derived by straightforward application of the implicit function theorem. The effects of κ and σ on β and e are indeterminate because the relevant determinants cannot be clearly signed.

Finally, by the envelope theorem, the effect of a change in any exogenous parameter x on the firm's equilbrium profit is given by the partial derivative L_x. It is straightforward to verify that L_R, L_ϕ, and L_ξ are positive, while L_κ and L_σ cannot be signed unambiguously. QED

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