Firm-Specificity of Asset, Managerial Capability, and Labor Market Competition

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Abstract

We develop a model that captures the link between specificity of a firm's asset and capability of the firm's top management, two important sources of profitability. It contributes to strands of economics and management literature by proposing a logic through which firm-specificity and heterogeneity are determined endogenously through labor market competition. Higher importance of managerial capability raises labor mobility, which reduces firm-specificity of asset and human capital, and firm size, whereas higher importance of asset specificity yields opposite effects. We discuss how our model results can enrich a prediction of transaction cost economics on the relationship between uncertainty and governance structure. Also, we discuss implications of our model in the contexts of cross-stage comparisons within an industry's life-cycle and cross-country differences.

1 Introduction

Firms let their employees operate their assets to produce and sell goods and services. Specificity of a firm's asset and capability of its top management are two important sources of the firm's profitability. In this paper, we develop a new theoretical model that captures the link between specificity of a firm's asset and capability of the firm's top management, where the degree of firm-specificity is endogenously determined through firms' competition in the labor market.

In the resource-based view of the firm (Wernerfelt, 1984; Barney, 1991), firm-specificity of the asset, often referred to as heterogeneity of firm resources (physical capital, human capital, and organizational capital resources), has been identified as a critical source of sustained competitive advantage. The point here is that heterogeneity of firm resources enables a firm to conceive and implement a value-creating strategy that is unique and unable to be imitated by other firms, leading the firm to establish a sustained competitive advantage (Barney, 1991). Among the three broad categories of firm resources just mentioned, in this paper we focus on physical capital resources, human capital resources, and the interaction between the two.

In transaction cost economics (Williamson, 1979; 1985), firm-specificity of an asset, referred to as asset specificity, also serves as a key concept in the analysis of governance structure. If a seller tailors the nature of its physical capital specifically to its transactions with a buyer, the seller can increase efficiency of its production for the buyer (Williamson, 1979; Riordan and Williamson, 1985). Furthermore, there is an important link between relation specificity of physical capital and human capital, because, if employees operate firm-specific physical capital, their training and learning-by-doing to operate the physical capital also become firm-specific (Williamson, 1979). In our theoretical model, we incorporate this link, which is a key element for the endogenous determination of firm-specificity of asset and human capital in the presence of labor market competition.

The capability of a firm's top management is a critical determinant of the firm's profitability, because it is the top management that sets the strategy for the firm, determines its organizational structure, and establishes systems and processes for implementing the strategy (Porter and Nohria, 2010). It has been widely recognized that the capabilities of top managements differ across firms. Several papers have explored theoretical models in which an individual with higher managerial talent assumes a top position of a larger firm (see Lucas, 1978; Rosen, 1982; Gabaix and Landier, 2008; Terviö, 2008).[1]

In our model, a firm that has realized a high managerial capability hires some workers from a firm that has realized a low managerial capability. The labor mobility generated by *ex ante* uncertainty of firms' managerial capabilities plays a key role in the endogenous determination of firm-specificity of asset and human capital. It has been widely recognized that capabilities of top managements are mostly innate, uncertain, and *ex ante* unknown.[2] Given the uncertainty, Pan, Wang and Weisbach (2015) empirically study the process through which the market learns about the CEO's ability, and Denis, Denis and Walker's (2015) empirical study concludes that the need for assessment of the CEO's ability is an important element of the structure of newly formed boards. Closely related to the uncertainty of top managements' capabilities, several papers have studied firm-dynamics models in which the efficiency of firms in an industry is different across firms, and no firm knows its own true efficiency *ex ante* (Jovanovic, 1982; Lippman and Rumelt, 1982; Hopenhayn, 1992).

The importance of top management's capability (hereafter referred to as managerial capability) differs across an industry's life cycle, countries, and time. For instance, as an industry evolves from infancy stage, firms typically undergo revolutionary technological changes. Thus, a business's success depends on the quality of its strategic decision making because firms during this stage are surrounded by a high level of uncertainty about the needs of customers, the products and services that will prove to be the most desired, and the best configuration of activities and technologies to deliver them. Whereas in the mature phase of an industry, institutional structures become clear and the opportunity for radical innovation is few. These arguments suggest that the importance of managerial capability is higher during the early phase of an industry's life cycle with revolutionary technological changes and higher level of uncertainty, while the importance tends to be lower in the mature phase of an industry with less technological advancement and lower

[1] See also Oi (1983) for a related analysis.

[2] As Goleman (1998) puts it, "Every business person knows a story about a highly intelligent, highly skilled executive who was promoted into a leadership position only to fail at the job. And they also know a story about someone with solid—but not extraordinary—intellectual abilities and technical skills who was promoted into a similar position and then soared. See also Aaker (2011), who points out that a gifted CEO needs two qualities, executive talent and strategic judgement, which come with birth, and not training in his view.

level of uncertainty.

How do differences in the importance of managerial capability affect firm-specificity of assets, the nature of human capital acquisition within firms, firm size, and labor mobility? Our two-period duopoly model of labor market competition provides an answer to this question. We find that, as the importance of managerial capability increases, firms make their asset less firm-specific, a smaller number of workers are hired (implying smaller average firm size), and labor mobility increases. Also, lower firm-specificity of asset leads to lower firm-specificity of skills acquired by workers.

The logic behind our result is as follows. In period 1, each firm hires a certain number of workers and determines the degree of firm-specificity of its asset (physical capital) without knowing its own managerial capabilities. As the importance of managerial capability increases, each firm anticipates that a larger number of workers switch their employers in period 2. This is because the higher importance of managerial capability makes firms' productivity more sensitive to their managerial capabilities, implying that period 2 productivity between a high-capability and a low-capability firm becomes larger. Anticipation of the higher labor turnover rate decreases a firm's incentive to invest in raising firm-specificity of its asset, because higher firm-specificity of the asset increases its worker's period 2 output only if the worker is already familiarized with firm-specific nature of the firm's asset through period 1 employment in the same firm. Lower asset specificity increases transferability of the firm's employees skills to the other firm and hence reduces firm-specificity of their human capital. The link between asset specificity and firm-specificity of human capital, not emphasized in the existing literature, is a driving force of our key results.

A higher labor turnover rate leads to lower firm-specificity of the asset, which, in turn, reduces each firm's incentive to hire workers in period 1, through two channels. First, lower firm-specificity reduces period-2 output of a retained worker. Second, lower firm-specificity increases the fraction of workers who switch employers in period 2. These two effects together reduce the expected period-2 productivity of each period-1 worker, implying that the number of workers employed by each firm in period 1 decreases as the importance of managerial capability increases.

Our theoretical framework yields empirical implications and predictions from a previously unexplored perspective. First, it enriches a prediction of transaction cost economics (TCE) on the relationship between uncertainty and governance structure by indicating that uncertainty has an indirect effect on vertical integration transmitted through asset specificity. In TCE, the three critical dimensions for characterizing transactions are uncertainty, the frequency with which transactions recur, and the degree to which transaction-specific investments are incurred (that is, the degree of asset specificity) (Williamson, 1979; 1985). A standard prediction of TCE is that, in line with asset specificity and frequent transactions, higher uncertainty makes vertical integration more likely. This TCE prediction holds true in our framework when uncertainty's positive direct effect outweighs its negative indirect effect; while the opposite relationship, not compatible with TCE prediction, is also consistent with it. Existing empirical evidence on this TCE prediction, in fact, are rather mixed, suggesting that channels through which uncertainty affects the likelihood of vertical integration can be richer than the standard one. Our analysis contributes to the TCE literature by pointing out a possible new channel and its implication in estimation. See Section 5.1 for details.

Furthermore, given that the importance of managerial capability can differ as an industry goes through stages of its life cycle, our model predicts that labor mobility is higher, specificity of asset and human capital is lower, and average firm size is smaller in the early or growing phases of an industry's life cycle that features rapid change of markets and disruptive technologies. Also, as the economy makes a transition from industrial capitalism to post-industrial capitalism, modern economies are becoming increasingly knowledge-intensive which renders the disadvantage to the firms that heavily rely on physical assets. This aspect allows us to apply the model results in explaining the observed difference in the labor mobility, specificity of asset and human capital, and firm size across countries and time (see Section 5.2 and 5.3 for more discussions).

2 Relationships with literature

As mentioned in the previous section, our theoretical analysis makes a contribution to TCE by proposing a new prediction on the relationship between uncertainty and governance structure. In this section, we discuss our contributions to the resource-based view (RBV) of the firm and the human capital theory. In the RBV literature, several authors have pointed out the importance of developing a theory in which firm heterogeneity, the central concept of the RBV, is determined endogenously rather than assumed exgonenouly (see Mahoney and Pandian, 1992; Helfat and Peteraf, 2003; Hoopes, Madsen and Walker, 2003). Mahoney and Pandian (1992), for example, point out, "A major advancement in the strategy field is the development of models where firm heterogeneity is an endogenous creation of economic actors."

As mentioned earlier, several papers have previously explored models in which an individual with higher managerial talent assumes a top position of a larger firm (Lucas, 1978; Rosen, 1982; Gabaix and Landier, 2008; Terviö, 2008). These papers can be viewed as contributions to the RBV literature because they analyse the process in which the distribution of managerial capabilities endogenously determines the size distribution of firms, where the difference in firm size is an important element of firm heterogeneity.

Our contribution to the RBV literature is complementary to these earlier contributions. As in these models, the distribution of managerial capabilities (which is assumed to be binary in our model for simplicity) is the driving force of firm heterogeneity in our model. However, elements of firm heterogeneity determined endogenously and the logic behind the determination in our model are fundamentally different from those in the earlier models. That is, in our model, firm heterogeneities of physical capital and human capital are the key elements that are endogenously determined, and these heterogeneities in turn lead to heterogeneity in firm size as well.

Labor mobility generated by *ex ante* uncertainty of managerial capabilities and the link between firm-specificities of asset and human capital are the driving forces of firm heterogeneities of physical capital and human capital, which in turn determine the average firm size in our model. Consistent with the earlier models, our model also captures the idea that a firm with higher managerial capability ends up with a larger firm size in the sense that some workers move from a low capability firm to a high capability firm in our model. See Murphy and Zabojnik (2004) for a related model, which analyze interconnections among the CEO's managerial capability, firm-specificity of the capability, and the optimal firm size. Murphy and Zabojnik (2004) show that, as the relative importance of firm-specific managerial capability decreases, the importance of the match between managerial capability and firm size increases, implying that filling CEO positions with outside hires rather than internal candidates become more likely. Firm-specificity of managerial capability is an exogenous parameter in their model.

Parallel to our contribution to the RBV literature, we contribute to the human capital theory literature by analysing the process in which firm-specificity of human capital is endogenously determined. Since the seminal contribution by Becker (1962), the distinction between general and firm-specific human capital has played an important role in the literature. Firm-specific human capital raises the productivity of the worker at his current firm but not elsewhere, whereas general human capital increases the worker's productivity at his current firm and at other firms.

To the best of our knowledge, firm-specificity of human capital is exogenously assumed in most exisiting models of human capital, but there are several recent exceptions including Morita (2001) and Lazear (2009). Our contribution to the literature is complementary to these earlier contributions, but the nature and the logic behind determination of firm-specificity in our model are fundamentally different from those in their models.

Morita (2001) proposes a model of labor market competition in which multiplicity of equilibria provides an explanation for the U.S.-Japanese differences in employment practices and the nature of technological improvement. The model assumes that, if a firm conducts continuous process improvement, the firm's technology is improved but a degree of firm-specificity is introduced. The link between continuous process improvement and the firm-specificity of training, along with labor mobility generated by stochastic worker-firm match qualities, lead to strategic complementarity, which in turn causes multiplicity of equilibria. In the Japanese equilibrium, each firm conducts continuous process improvement because other firms do so, and as a consequence training provided by such a firm becomes less effective (more firm-specific) in other firms. This lowers the turnover rate, which, in turn, increases firms' incentives to train employees. In the U.S. equilibrium, training is general, which raises the turnover rate and decreases incentives to train.

Our model is related to Morita's (2001) model in the sense that the link between firm-specificity of asset and firm-specificity of human capital, a driving force of our results, is similar to the link between continuous process improvement and firm-specificity of training. The key logic and insight, however, are different. In our model, it is *ex ante* uncertainty of managerial capabilities, not worker-firm match qualities, that generates labor turnover. As the importance of managerial capability increases, firms anticipate a higher labor turnover rate, and this reduces asset specificity, firm-specificity of human capital, and firm size, in equilibrium. Comparative statics analyses with respect to the importance of managerial capability yield key results and implications in our model, whereas an explanation for cross-country differences based on multiplicity of equilibria, which does not arise in our model, is the key insight of Morita's (2001) model.

Notice that, regarding uncertainty, our focus is on uncertainty of managerial capability, whereas uncertainty in labour productivity is another important issue. Bai and Wang (2003) analyze a fixed wage contract model to study the effects of uncertainty in labor productivity on investment in firm-specific human capital (SHC), wage and the probability of separation. They find that wage and SHC are always positively correlated, but SHC investment and the probability of separation do not have a monotonic relationship. Human capital is assumed to be firm-specific in Bai and Wang's (2003) model, and hence endogenous determination of firm-specificity of human capital is not an issue there.

Lazear (2009) and Gathmann and Schönberg (2010) propose a new theory of human capital in which all skills are general but firms use them with different weights attached. The difference in skill-weights determines firm-specificity (or transferability) of the worker's skill set in their models. In Lazear's (2009) approach, workers are exogenously assigned to a firm and then choose how much to invest in each skill. In Gathmann and Schönberg's (2010) approach, each worker is endowed with a productivity in each skill and then chooses an occupation, where different occupations have different skill-weights. An important difference between these models and our model is that the difference in skill-weights is exogenously assumed in the former, whereas the degree of firm-specificity is endogenously determined in the latter.

3 The model

Consider an industry with two *ex ante* identical firms, firms 1 and 2, in a two-period setting. Period 1 is the skill acquisition period and period 2 is the production period. Only one homogenous good is produced in this industry and its price is fixed and normalized to one.[3] A firm's output is a summation of its employees' outputs. There exists

[3]The fixed-price assumption allows us to focus our analysis on labor market competition. Analysis of the interaction between labor and product market competition is beyond the scope of this paper and left to future research.

a large number of individuals, where each individual is of measure zero. In each period, labor supply is perfectly inelastic and fixed at one unit for each individual. To keep the analysis simple, firms and individuals do not discount the future, and they are risk-neutral.

At the beginning of period 1, each individual looks identical and can apply to a firm for employment. Each firm i ($i = 1, 2$) simultaneously makes a first-period wage offer $w_{i,1}$ to hire a desired number of individuals from its applicants. Let n_i denote the number of firm i's first-period employees. Individuals not employed by a firm earn per-period reservation wage $\omega > 0$ outside the industry. At the same time, each firm i chooses a level of investment $z_i \geq 0$ in its asset specificity at a cost of $c(z_i) \geq 0$, where $c(\cdot)$ is a convex function. The asset specificity refers to the extent to which a firm tailors its non-human asset for its particular use. To obtain closed-form solutions in the analysis, let $c(z) = \frac{1}{2}\theta z^2$ and $\theta > 0$.

Any worker employed by a firm in period 1 (which is the skill acquisition period) produces zero output in that period. Hence each firm i's period 1 profit is

$$-\frac{1}{2}\theta z_i^2 - W_{i,1},$$

where $W_{i,1}$ denotes firm i's first-period total wage bill.

In order for a worker to produce any output in a firm in period 2, the worker must acquire skills in a firm in this industry in period 1. Any worker employed by a firm acquires a certain level of industry specific skill, which increases the worker's second-period output by d (a positive constant). At the same time, the worker gets familiarized with the specificity of his first-period employer i's asset in period 1. If the worker is retained by the same firm in period 2, his familiarity with asset specificity increases his second-period output by $f(z_i)$, where $f(0) = 0$ and $f'(z_i) > 0$ for all $z_i \geq 0$. That is, a higher level of asset specificity increases a worker's second-period output if the worker has already been familiarized with it. Taken together, if a worker stays with his period 1 employer i in period 2, his second-period output increases by $d + f(z_i)$, whereas, if a worker switches his employers between periods 1 and 2, his second-period output increases by d. To obtain closed-form solutions, let $f(z_i) = sz_i$ where $s > 0$. Here s captures the importance of a firm's asset specificity on its retained workers.

Each firm i's production efficiency is affected by its managerial capability denoted a_i. The realization of a_i is governed by a mean-preserving shock according to a symmetric binary distribution with $\Pr(a_i = x) = \Pr(a_i = -x) = \frac{1}{2}$. Each firm i's managerial capability is unknown to every firm and individual including firm i itself at the beginning of period 1, and it realizes and becomes common knowledge at the end of period 1. This specification is consistent with the widely held view that the ability of a firm's top management is mostly innate, and difficult to observe or assess *ex ante*.

Higher managerial capability a_i increases firm i's worker's second-period output by x, whereas lower managerial capability decreases it by x. Notice that the difference of managerial capabilities between a high-capability and a low-capability firm, $2x$, represents the sensitivity of firms' production efficiency to their managerial capabilities. Hence we interpret that the parameter x represents the importance of managerial capability, which increases as firms' productivity becomes more sensitive to the difference of their managerial capabilities.[4]

Production in period 2 requires employer supervision. Assume that firm i's per worker supervision cost is bn_i where $b > 0$. That is, as the number of workers increases, each worker's net output declines because each worker receives less supervision from the employer. See Zábojník and Bernhardt (2001) and DeVaro and Morita (2013) for a similar modeling choice.

At the beginning of period 2, each firm i can make its second-period wage offer w_{ij} ($i \neq j$) to poach firm j's employees, and can also make offer w_{ii} to retain its period 1 employees. Each worker can apply for one firm, or apply for no firms to take an outside option and earn ω. Each firm can hire a desired number of workers from its applicants. If a worker applied for a firm and not hired, the worker takes an outside option. Note that, although it is possible for a firm to employ a worker from outside the industry by offering ω as the second-period wage, no firms have incentives to do so because such a worker's period 2 output would be zero.

When a firm makes wage offers, it knows its realization of managerial capability. Hence, the wage offer can be different across retained workers and new hires. Let $|m_i|(>$

[4] The realization of a_i can also be more generally interpreted as the realization of firm-specific productivity shock, where x can be interpreted representing the extent of the shock. Given that *ex ante* uncertainty of managerial capability is an important element of firm-specific productivity shock, we adopt more specific interpretation and elaborate on implications that arise from such an interpretation.

n_i) denote either the number of firm i's newly hired workers in the second period if $m_i \geq 0$, or the number of dismissed workers if $m_i < 0$. Each firm i's period 2 profit is

$$\begin{cases} n_i(a_i + d + sz_i) + m_i(a_i + d) - b\,(n_i + m_i)^2 - W_{i,2} & \text{if } m_i \geq 0 \\ (n_i + m_i)\,(a_i + d + sz_i) - b\,(n_i + m_i)^2 - W_{i,2} & \text{if } m_i < 0 \end{cases},$$

where $W_{i,2}$ denotes firm i 's second-period total wage bill. Firm i expands in its firm size if the net change in the number of workers in period 2 is positive; firm i contracts in its firm size if the net change in the number of workers is negative. A firm stays unchanged in its size only if it does not expand nor contract.

The timing of the game is as follows.

Period 1

[Stage 1] Each individual can apply to a firm or earn per-period reservation wage $\omega > 0$ outside the industry. Each firm i simultaneously makes first-period wage offers $w_{i,1}$ to hire desired number of individuals from its applicants, where $i = 1, 2$. At the same time, each firm chooses its level of asset specificity z_i by incurring a cost.

[Stage 2] Each firm i's managerial capability a_i is realized and becomes common knowledge.

Period 2

[Stage 3] Each firm i can offer $w_{ij} (i \neq j)$ to the other firm's period 1 employees, and can offer w_{ii} to retain its period 1 employees. Each worker can apply for one firm. Each firm can hire a desired number of workers from its applicants.

[Stage 4] Each firm i produces the good according to its workers' production efficiency, in which each retained worker produces $a_i + d + sz_i$ units and each new worker produces $a_i + d$ units.

4 Analysis

In this section, we consider the symmetric Subgame Perfect Nash Equilibria (SPNE) in pure strategy. That is, each firm i chooses the same level of asset specificity and hires the same number of first-period workers in equilibrium.

We focus on equilibria in which both firms continue operation in period 2 and a strictly positive number (measure) of workers leave the low-capability firm and all of them move to the high-capability firm at the beginning of period 2 whenever the realizations of managerial capability are different in both firms,[5] given that in reality expansion and contraction of firm size are common in most industries. Proposition 1 identifies necessary and sufficient conditions for such an equilibrium to exist, and characterizes the equilibrium. Proposition 2 and 3 then present comparative statics results on the level of asset specificity, the firm size and the expected labor turnover rate in the equilibrium. Note, all proofs are in the Appendix.

Suppose that there exists an equilibrium in which a strictly positive number of workers switch employers in period 2 when firms' managerial capabilities are different. Consider a Stage 3 subgame in which each firm i chose z_i level of asset specificity and hired n_i workers at Stage 1 and the uncertainty of managerial capability was realized at Stage 2. There are four cases, namely $a_i > a_j$, $a_i < a_j$, $a_i = a_j = x$, and $a_i = a_j = -x$. First consider the case where firm i realizes its higher managerial capability and firm j realizes its lower capability; $(a_i, a_j) = (x, -x)$. If firm i expands in its firm size by hiring m_i (> 0) new workers from firm j, firm i makes offer w_{ij} such that the marginal productivity of j's first-period employees in i, i.e. $d + x - 2b(n_i + m_i)$, is equal to w_{ij} subject to the conditions that $w_{ij} \geq w_{jj}$ and $w_{ij} \geq \omega$ where w_{jj} is firm j's retention wage for its period 1 employees. Firm j, on the other hand, contracts in its firm size and is willing to offer $w_{jj} = d - x + sz_j - 2b(n_j + m_j)$ to retain $n_j + m_j$ period 1 employees where $m_j < 0$. Also, firm i makes offer w_{ii} to retain its period 1 employees such that w_{ii} equals to their outside option in firm j. That is, $w_{ii} = d - x - 2b(n_j + m_j)$.

In the equilibrium, $m_i = -m_j$ and both firms offer the same second-period wage to the workers in firm j such that $w_{ij} = w_{jj}$.[6] We obtain that the equilibrium second-period wage for workers retained in firm j and newly hired in firm i is $d + \frac{1}{2}sz_j - b(n_i + n_j) \equiv w^E_{-i,2}(n_i, z_j, n_j)$, and the number of workers moving across firms in equilibrium is

$$m^E_i(n_i, z_j, n_j) \equiv \frac{1}{4b}[2x - sz_j - 2b(n_i - n_j)], \tag{1}$$

[5]The qualitative nature of our results would remain unchanged under parameterizations in which some workers leaving the low-capability firm leave the industry to take up an outside option in equilibrium.

[6]See Appendix for the details in which firm i contracts or retains only some of its period 1 employees can be ruled out in the equilibrium (see the proof of Lemma 1).

where $w^E_{-i,2}(n_i, z_j, n_j) \geq \omega$. That is, when a worker moves from low-capability to high-capability firms, the net gains comes from (1) low capability firm's wage saving in workers' industry specific human capital and their familiarization of the firm's asset, and the reduced saving in supervision, and (2) high-capability firm's productivity gain of workers' industry specific human capital and the increased supervision cost. Those net gains are now equally shared by both firms—each paying $d + \frac{1}{2}sz_j - b(n_i + n_j)$. Firm i's retention wage for its period 1 employees in equilibrium, denoted $w^E_{i,2}(n_i, z_j, n_j)$, becomes $d - \frac{1}{2}sz_j - b(n_i + n_j)$.[7] Note that, in the case where firm i expands and firm j contracts in the equilibrium, the following condition must hold:

$$0 < m^E_i(n_i, z_j, n_j) < n_j. \tag{2}$$

The right-hand side of condition (2) holds with strictly inequality; otherwise, firm j will shut down. Hence, in the SPNE outcome where $a_i > a_j$, firm i's second-period profit is given by

$$\begin{aligned} \pi^E_i(z_i, n_i, z_j, n_j) \quad \equiv \quad & n_i(d + x + sz_i) + m^E_i(n_i, z_j, n_j)(d + x) - b(n_i + m^E_i(n_i, z_j, n_j))^2 \\ & -(n_i w^E_{i,2}(n_i, z_j, n_j) + m^E_i(n_i, z_j, n_j) w^E_{-i,2}(n_i, z_j, n_j)). \end{aligned} \tag{3}$$

Next consider the case where firm i learns its lower managerial capability and firm j learns its higher capability; $(a_i, a_j) = (-x, x)$. Let $w^C_{i,2}(z_i, n_i, n_j)$ and $m^C_i(z_i, n_i, n_j)$ be defined analogously given firm i contracts in its firm size by retaining only some of its period 1 employees. In the similar vein as the analysis in previous case, we obtain that firm i's second-period profit conditional on $a_i < a_j$ is given by[8]

$$\begin{aligned} \pi^C_i(z_i, n_i, n_j) \quad \equiv \quad & (n_i - m^C_i(z_i, n_i, n_j))(d - x + sz_i) - b(n_i - m^C_i(z_i, n_i, n_j))^2 \\ & -(n_i - m^C_i(z_i, n_i, n_j)) w^C_{i,2}(z_i, n_i, n_j). \end{aligned} \tag{4}$$

Now consider a Stage 3 subgame where both firms realize the same managerial capabilities, $a_i = a_j$. In this case, a firm's period 1 employee has the same expected

[7] Although expansion firm i's retention wage $w^E_{i,2}(n_i, z_j, n_j)$ can be binding given $w^E_{-i,2}(n_i, z_j, n_j) > w^E_{i,2}(n_i, z_j, n_j)$ in equilibrium, each firm i's profit function does not depend on whether $w^E_{i,2}(n_i, z_j, n_j)$ binds or not (see footnote 9 for a discussion).

[8] The condition $0 < m^C_i(z_i, n_i, n_j) < n_i$ is the same as condition (2) in the equilibrium given that we focus on symmetric equilibrium.

productivity in the other firm. Each firm i thus offers the same second period wage to the workers in the other firm. Hence, in the equilibrium there is no labor mobility. That is, each firm retains all of its first-period employees and stays unchanged in its firm sizes. Let $w_{i,2}^S(n_i;a_i) \equiv d + a_i - 2bn_i$ when each firm i has the same capability. Then firm i's second-period profit conditional on $a_i = a_j$ is given by

$$\pi_i^S(z_i, n_i; a_i) \equiv n_i(d + a_i + sz_i) - bn_i^2 - n_i w_{i,2}^S(n_i; a_i). \tag{5}$$

Note that $w_{i,2}^E(n_i, z_j, n_j) \geq \omega$ implies $w_{i,2}^S(n_i; a_i = x) > \omega$ since $w_{i,2}^S(n_i; a_i = x) = d+x-2bn_i > w_{i,2}^E(n_i, z_j, n_j)$ in equilibrium with positive labor turnover; while $w_{i,2}^S(n_i; a_i = -x)$ can be binding since $w_{i,2}^S(n_i; a_i = -x) < w_{i,2}^E(n_i, z_j, n_j)$.

Therefore, given that a strictly positive number of workers move across firms in equilibrium whenever $a_i \neq a_j$, each firm i's expected profit in period 2 is

$$\begin{aligned} \pi_{i,2}(z_i, n_i, z_j, n_j) \quad \equiv \quad & \Pr(a_i > a_j)\pi_i^E(z_i, n_i, z_j, n_j) + \Pr(a_i < a_j)\pi_i^C(z_i, n_i, n_j) \\ & + \Pr(a_i = a_j)\pi_i^S(z_i, n_i; a_i), \end{aligned} \tag{6}$$

where the probability of each outcome (a_i, a_j) is $\frac{1}{4}$.

At Stage 1, each firm i offers the first-period wage $w_{i,1}$ to hire individuals from its applicants An individual who receives an offer from firm i at Stage 1 anticipates his/her second-period wage will be $w_{i,2}^E(n_i, z_j, n_j)$ if $a_i > a_j$ at Stage 3, $w_{i,2}^C(z_i, n_i, n_j)$ if $a_i < a_j$, and $w_{i,2}^S(n_i; a_i)$ if $a_i = a_j$. Since there is a large number of *ex ante* identical and risk-neutral individuals, and that every individual can earn a reservation wage ω per period outside the industry, firm i in equilibrium chooses $w_{i,1} = w_{i,1}(z_i, n_i, z_j, n_j)$ such that $w_{i,1}(z_i, n_i, z_j, n_j) + E[w_{i,2}(z_i, n_i, z_j, n_j)] = 2\omega$ holds where $E[w_{i,2}(z_i, n_i, z_j, n_j)]$ is given by

$$\begin{aligned} E[w_{i,2}(z_i, n_i, z_j, n_j)] \quad \equiv \quad & \Pr(a_i > a_j)w_{i,2}^E(n_i, z_j, n_j) + \Pr(a_i < a_j)w_{i,2}^C(z_i, n_i, n_j) \\ & + \Pr(a_i = a_j)w_{i,2}^S(n_i; a_i). \end{aligned} \tag{7}$$

Given that firm i's period 1 profit is $-\frac{1}{2}\theta z_i^2 - W_{i,1}$, firm i's expected overall profit is

$\Pi_i(z_i, n_i, z_j, n_j)$ in equilibrium where[9]

$$\Pi_i(z_i, n_i, z_j, n_j) \equiv -\frac{1}{2}\theta z_i^2 - n_i w_{i,1}(z_i, n_i, z_j, n_j) + \pi_{i,2}(z_i, n_i, z_j, n_j). \tag{8}$$

In equilibrium, firm i chooses (z_i, n_i) to maximize $\Pi_i(z_i, n_i, z_j, n_j)$. The necessary first-order conditions that define the equilibrium level of asset specificity and the number of first-period workers are $(\partial/\partial z_i)\Pi_i(z_i^*, n_i^*) = 0$ and $(\partial/\partial n_i)\Pi_i(z_i^*, n_i^*) = 0$ for each firm i. Given that we focus on symmetric equilibrium, we have $(z_i^*, n_i^*) = (z_j^*, n_j^*) \equiv (z^*, n^*)$. This implies Lemma 1.

Lemma 1. *Suppose that there exists a symmetric equilibrium in which a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm in period 2 when firms' managerial capabilities are different. The unique equilibrium level of asset specificity and the equilibrium number of first-period workers are*

$$(z^*, n^*) = (\frac{16s(d-2\omega) - 2sx}{32b\theta - 17s^2}, \frac{(32b\theta - s^2)(d-2\omega) - 2s^2x}{2(32b\theta - 17s^2)}), \tag{9}$$

where $\omega \leq \frac{s^2(8d-x)}{32b\theta - s^2}$.

Note that in equilibrium the condition (2)—$0 < m_i^E(n^*, z^*, n^*) < n^*$—must hold, where $m_i^E(n^*, z^*, n^*)$ equals $\frac{1}{4b}(2x - sz^*)$ if the second-period wage for workers who switch employers is not binding, and it equals $\frac{1}{2b}(d + x - \omega) - n^*$ if the wage is binding. It implies there exists an intermediate range of x in which a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm in period 2 only if x is within that range.

Lemma 2. *There exist unique values* $\underline{x}$ *and* $\bar{x}$ *where* $0 < \underline{x} < \bar{x}$ *such that* $(z_i^*, n_i^*) = (z_j^*, n_j^*) = (z^*, n^*)$ *holds only if* $x \in (\underline{x}, \bar{x})$.

Lemma 2 tells us that $x \in (\underline{x}, \bar{x})$ is necessary for the existence of a symmetric equilibrium in which a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm whenever $a_i \neq a_j$. Proposition 1

[9] In the expression of $\Pi_i(z_i, n_i, z_j, n_j)$, the expected second-period wage payment is cancelled out if workers stay with their first-period employer since a firm's wage payment in period 1 is determined by $2\omega - E[w_{i,2}(z_i, n_i, z_j, n_j)]$. That is, $\Pi_i(z_i, n_i, z_j, n_j)$ does not depend on $w_{i,2}^E(n_i, z_j, n_j)$ and $w_{i,2}^S(n_i; a_i)$, but depends on the wage for workers who switch employers.

below further shows that this condition is not only necessary but also sufficient, and the equilibrium is unique under this condition.

Proposition 1. *For any given parameterization, there exist unique values $\underline{x}$ and $\bar{x}$ where $0 < \underline{x} < \bar{x}$ such that the following property holds: There exists a unique symmetric equilibrium choices of asset specificity and number of first-period workers in which a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm whenever the realizations of both firms' managerial capabilities are different in period 2, if and only if $x \in (\underline{x}, \bar{x})$.*

Proposition 1 can be understood as follows. If the difference between high and low managerial capability is too small, labor mobility will not occur since the workers in the firm facing low capability still have relatively high productivity once been retained. If the difference between high and low managerial capability is too large, a firm underwent contraction will completely shut down given that the productivity of its workers is relatively high in its rival firm.

Notice that in equilibrium $m_i^E(n^*, z^*, n^*) = m_i^C(z^*, n^*, n^*) \equiv m^*$ and $w_{-i,2}^E(n^*, z^*, n^*) = w_{j,2}^C(z^*, n^*, n^*) \equiv w_2^{Switch}$, and let $w_{i,2}^E(n^*, z^*, n^*) \equiv w_2^{Retain}$ and $w_{i,1}(z^*, n^*, z^*, n^*) \equiv w_1^*$. Then, in the equilibrium each firm chooses the level of asset specificity z^*, makes first-period wage offer w_1^* to hire n^* workers at Stage 1. At Stage 3, all period 1 employees stay in the industry for all realizations of (a_i, a_j). If both firms have different managerial capabilities, firm i who realizes higher managerial capability retains all its first-period employees at wage w_2^{Retain} and expands in its firm size by hiring m^* workers from firm j ($j \neq i$) at wage w_2^{Switch}, whereas firm j contracts in its firm size and retains $n^* - m^*$ workers at second-period wage w_2^{Switch}. Hence if $a_i \neq a_j$, a strictly positive number of workers, m^*, leave the low-capability firm and all of them move to the high-capability firm in the equilibrium. At Stage 3 if $a_i = a_j$, each firm i retains all its first-period workers at the second-period wage $w_{i,2}^S(n^*; a_i)$ and stays unchanged in its firm size; thus there is no labor mobility. Then, the expected number of workers who switch their employers at the beginning of period 2 is $\frac{1}{2}m^*$, and each firm i's expected labor turnover rate is $\frac{m^*}{2n^*}$ in the equilibrium.

We will now turn to comparative statics on the equilibrium level of asset specificity z^*, firm size n^*, and the expected equilibrium turnover rate $\frac{m^*}{2n^*}$. Note that the period 1 number of workers n^* can be interpreted as average firm size, measured by employment, since n^* determines each firm's expected number of workers over two periods.

Proposition 2. *As the importance of managerial capability (captured by x) increases, the level of asset specificity decreases, the average firm size decreases, and the expected labor turnover rate increases in the equilibrium.*

The key result here is that, as the importance of managerial capability increases, the expected number of workers who switch their employers (expected labor mobility) in period 2 becomes larger, and each firm's asset specificity and average employment size decreases. The logic behind this result can be explained as follows. When firm i chooses the level of its asset specificity and the number of workers it employs in period 1, it estimates the expected number of its first-period employees that the firm will retain for second-period operation, and the expected number of workers that the firm hires from its rival firm j in period 2. A higher importance of managerial capability increases the difference of period 2 productivity between a high-capability and a low-capability firm. Then, as the importance of managerial capability increases, each firm anticipates a larger number of workers switch their employers in period 2 if both firms' managerial capabilities turn out to be different. Hence a higher importance of managerial capability decreases the expected number of retained workers, and it increases the expected number of workers who switch employers. Holding the initial number of workers constant, this reduces each firm's incentive to choose higher specificity of its asset. This is because higher firm-specificity increases a worker's period 2 productivity only if the worker was employed by the same firm in period 1 to be familiarized with the nature of the firm-specificity.

Lower firm-specificity of asset, in turn, reduces each firm's incentive to hire workers in period 1 through two channels. First, lower firm-specificity reduces period 2 output of a retained worker. Second, lower firm-specificity increases the fraction of workers who switch employers in period 2 if the two firms realize different managerial capability. These two effects together reduce the expected period 2 productivity of each period 1 worker, implying that the number of workers employed by each firm in period 1 decreases as the importance of managerial capability increases. The last result of Proposition 2 naturally follows from the key result mentioned above. As the importance of managerial capability increases, the expected labor turnover rate, measured by the ratio of expected number of workers who switch their employers in period 2 to the number of first-period workers, increases unambiguously in the equilibrium.

Proposition 3. *As the importance of a firm's asset specificity (captured by s) increases, the level of asset specificity increases, the average firm size increases, and the expected labor turnover rate decreases in the equilibrium.*

Recall that in period 1 firm i estimates the number of workers it will retain and hire from the rival firm in period 2, respectively. As the importance of firm i's asset specificity increases, firm i will retain more of its first-period employees during the contraction phase, while hire fewer workers from its rival during the expansion phase since new workers become relatively less productive in firm i. This implies that each firm anticipates a smaller number of workers switch their employers in period 2 if the realized managerial capabilities are different. Lower expected labor mobility, along with the higher return from retained workers (captured by s), implies that a firm has higher incentive to choose a higher level of asset specificity. These two effects are mutually reinforcing because the higher level of asset specificity reduces the expected turnover rate by increasing the retained workers' productivity. The results of the average firm size and expected turnover rate follow through the logic analogous to the one explained for Proposition 2.

5 Discussion

5.1 An application to the TCE prediction on uncertainty

Our theoretical framework enriches a prediction of TCE on the relationship between uncertainty and governance structure. As mentioned in Introduction, a standard prediction of TCE is that, in line with asset specificity and frequent transactions, higher uncertainty makes vertical integration more likely. The key idea behind this prediction is that vertical integration can prevent *ex post* opportunism associated with asset specificity and uncertainty at the cost of integration. Then, higher uncertainty increases the loss due to *ex post* opportunism, implying that the net benefit of vertical integration becomes positive when uncertainty becomes sufficiently high.

Consider an extension of the model that the industry consists of two sectors of production, upstream and downstream. The downstream sector is the same as our duopoly environment. While each downstream firm now needs to obtain an intermediate product from its supplier in the upstream sector, and transform it into the homogeneous final product. In the beginning of period 1, each downstream firm can choose modes of governance—vertically integrated with its upstream supplier or not. This setup incorporates uncertainty of each downstream firm's managerial capability, where the degree of uncertainty increases as the importance of managerial capability increases.

In this setup, higher uncertainty affects vertical integration not only directly but also indirectly. To see the indirect effect, recall that higher uncertainty increases labor mobility, which in turn reduces the degree of each firm's asset specificity. Lower degree of asset specificity decreases the loss due to *ex post* opportunism. This reduces the net benefit of vertical integration, working in the direction of making vertical integration less likely. That is, our model implies a mediation process where the uncertainty (exogenous variable) affects vertical integration through asset specificity (an intermediate variable or a mediator).

Given such mediation process, further consider the estimation of following structural equations :

$$Y_i = \beta_0 + \beta_1 M_i + \beta_2 X_i + \epsilon_{i1}, \quad (10)$$

$$M_i = \gamma_0 + \gamma_1 X_i + \epsilon_{i2}, \quad (11)$$

where X_i and M_i represents the observed level of uncertainty and asset specificity, respectively, and Y_i is the observed vertical integration choice.[10] In this mediation process, the total effect of the uncertainty can be decomposed into direct and indirect effects. The direct effect equals the effect of uncertainty on vertical integration choice that is not transmitted by the mediator—asset specificity. This direct effect thus corresponds to the TCE prediction where the coefficient β_2 is positive. On the other hand, our model points out that there exists an indirect effect of the uncertainty on vertical integration going through asset specificity, in which the coefficient γ_1 is negative. The total effect of the uncertainty on vertical integration thus equals $\beta_2 + \gamma_1\beta_1$. Notice that TCE predictions also require β_1 be positive. Hence, the sign of $\beta_2 + \gamma_1\beta_1$ is indeterminate.

[10]The key identification assumption for such causal mechanism, a process in which a causal variable of interest influences the outcome, is error terms ϵ_{i1} and ϵ_{i1} are uncorrelated. See Imai, Keele and Yamamoto (2010) and Imai, Keele, Tingley and Yamamoto (2011) for the proofs and discussions under which $\hat{\gamma_1}\hat{\beta}_1$ is a valid estimator (i.e., asymptotically consistent) of the indirect (mediation) effect.

When uncertainty's (negative) indirect effect outweighs its (positive) direct effect, our model predicts that uncertainty makes vertical integration less likely. This prediction is opposite to the standard TCE prediction. The structural equations thus imply a richer relationship between uncertainty and governance structure.

Another implication of this setting is that it highlights a twofold estimation challenge. First, an endogeneity problem exists in a regression model if only asset specificity is included in the explanatory variables. A similar point has been made by Macher and Richman (2008)'s empirical TCE review article. They state "Virtually all of the [empirical] studies examined in this survey treat the specificity of assets and the level of a firm's investment in those assets as exogenous. These are, however, choice variables ... should therefore be treated as endogenous." Here we identify one cause (i.e., exclusion of uncertainty) of such endogeneity of asset specificity.

Second, if the underlying regression model has the structure as in equations (10) and (11), estimating uncertainty effect in a single linear regression model with asset specificity included in explanatory variables as in equation (10) (i.e., without considering the indirect effect of uncertainty) results in multicollinearity problem. Because there is a linear relationship between uncertainty and asset specificity. Consequently, the resulting estimate can be either imprecise or numerically inaccurate even though it is not biased. Our structural equations thus reconcile the seemingly mixed results of uncertainty effect on vertical integration in TCE empirical literature.[11]

Specificially, Lieberman (1991) finds in his study of chemical products that volatility in the firm's downstream detrended market sales appears to have little influence on integration decisions. Anderson and Schmittlein (1984) find in their study of the electric components industry, "Contrary to the transaction cost model, neither frequency of transactions nor interaction of specificity and environmental uncertainty [forecast error in sales] is significantly related to integration." By using data from multiple industries, Norton (1988) finds in the industries of motels and refreshment places that detrended percentage variations in retail sales have negative effect on integration choice, in which the negative effect in the latter industry is significant. Notice that the studies referred to

[11] For review articles, see Shelanski and Klein (1995); Lafontaine and Slade (2007); Macher and Richman (2008). As argued by Macher and Richman (2008), although TCE predictions have earned empirical success in many of its central tenets, several prior empirical studies do not lend support to the role of uncertainty in the decision of vertical integration.

above adopt the variance of detrended sales or of forecasting errors or the instability of market shares as their empirical measures for uncertainty.[12] This uncertainty measure is consistent with our model environment since our model predicts that higher uncertainty results in higher labor mobility, leading to higher volatility of market share. But these empirical studies, in fact, test the TCE prediction that β_2 is positive, ignoring the indirect channel that our model identifies. As a result, their estimates are imprecise and may have sizable change due to high degree of multicollinearity. Also, the insignificant or negative sign of their uncertainty coefficient, despite not lending support to TCE prediction on the surface, can still be compatible under our setup.

5.2 An application to different phases of an industry's life cycle

The second application concerns the idea that the importance of managerial capability can differ as an industry goes through stages of its life cycle (Helfat and Peteraf, 2003). For example, as an industry evolves from infancy stage, firms typically undergo revolutionary technological changes that is characterized by Schumpeter's "creative destruction" (Agarwal, Sarkar and Echambadi, 2002; Winter, 1984). Thus, a business's success critically depends on the quality of its strategic decision making because firms during this stage are surrounded by a high level of uncertainty about the needs of customers, the products and services that will prove to be the most desired, and the best configuration of activities and technologies to deliver them. Whereas in the mature phase of an industry, institutional structures become clear and the opportunity for radical innovation is few. It follows that firms during this stage face lower level of uncertainty, and thus strategic decision making is less important for them.[13] These arguments suggest that the importance of managerial capability is higher during the early phase of an industry's life cycle with revolutionary technological changes and higher level of uncertainty, while the degree tends to be lower in the mature phase of an industry with less technological advancement and lower level of uncertainty. Our model then predicts that labor mobility is higher, specificity of asset and human capital is lower, and average firm

[12]This type of uncertainty measure, as mentioned by Lafontaine and Slade (2007), is common in the empirical literature.

[13]See also empirical study by Katila and Shane (2005). Using data on firms' efforts to commercialize technological inventions, they find that firms' innovation activity in response to market competitiveness differs depending on firm newness. Giving that entries of new firms occur mostly during the early stage of an industry's life cycle, this finding suggests that the importance of managerial capability differs across different life cycle stages.

size is smaller in the early or growing phases of an industry's life cycle and vice-versa in the later or mature phases.

These predictions are consistent with empirical and observational evidence. Concerning firm size, Dinlersoz and MacDonald (2009) show that average firm size, measured by employment (but not output), in U.S. manufacturing industries from 1963 until 1997 falls over time during the rapid entry phase of the industry's life-cycle, where the rapid entry phase occurs during the first stage of life cycle and when there exists greater technological improvement. In addition, using manufacturing firm data from Portugal, Italy, and Spain, respectively, Cabral and Mata (2003), Angelini and Generale (2008), and Segarra and Teruel (2012) all confirm that the firm size distribution of employees clearly skewed to the right (most of the mass is on small firms) and the skewness tends to diminish with firm age.[14] That is, the smaller the firm size, the younger the firm. Since young firms account for a much higher fraction in the starting stages of an industry's life cycle, this result also implies average firm size tends to be smaller during the earlier life cycle stages.

Concerning labor mobility, Benner (2002) studies labor markets in Silicon Valley and points out that, "The rapid turnover and volatility in employment in Silicon Valley is integrally connected to the nature of competition in the region's high-technology industries. In these industries, markets and technology change extremely rapidly and in unpredictable ways." Notice that, compared with U.S. automobile industry, Silicon Valley is considered as high-tech clusters consisting of relatively young firms or startups with concentrated entrepreneurship,[15] reflecting a growing stage of the industry evolution.

5.3 An application to U.S.-Japanese differences

The U.S. and Japan have been considered representing two contrasting employment systems, which attracts significant attention in the literature of international comparison in how internal labor markets operate. By capturing the interconnections among asset

[14] Cabral and Mata (2003) consider the cohort of firms that entered Portuguese manufacturing in 1984 and follow them until 1991. Angelini and Generale (2008) study the firm size distribution of employees by pooling Italian manufacturing firm data in 1992, 1995, 1998, and 2001. Segarra and Teruel (2012) use Spanish manufacturing firms data in both 2001 and 2006.

[15] Zhang (2003) shows that, in Silicon Valley, more than half of the 2002 top 40 technology companies were not even founded two decades ago.

specificity, acquisition of firm-specific human capital, managerial capability, and labor mobility, our model offers new explanations for and predictions on the U.S.-Japanese differences based on the cross-country differences in the importance of both managerial capability and firm-specificity of asset.

Acemoglu, Aghion and Zilibotti (2006) argue in their analysis of technology frontiers and firm selection that managerial skill is more important for undertaking innovative activities than for adopting and imitating existing technologies from the world technology frontier. They then point out, based on their analysis of the correlation between distance to the frontier and R&D intensity using data from the OECD sectoral database, that innovation becomes more important as the economy approaches the world technology frontier and there remains less room for adoption and imitation. Following their analysis and argument, we argue that the importance of managerial capability was substantially lower in Japan than in the U.S. when most Japanese industries were catching up with the West in the postwar growth period (Okimoto, 1989).

On the other hand, as the economy makes the transition from industrial capitalism to post-industrial capitalism, modern economies are becoming increasingly knowledge intensive which renders the disadvantage to the firms that heavily rely on physical assets. For example, Iwai (2002) points out that, in the new era of post-industrial capitalism, the physical assets have surrendered their central position to the knowledge-based human assets that money can no longer buy and control.[16] The advent of knowledge economy thus reduces the importance of firm-specificity of asset across the world. But different countries have different paths in making their transition to the knowledge economy. Based on the knowledge assessment methodology (KAM) developed by World Bank Institute that traces the challenges and opportunities of major economies' transition to knowledge-based economy from 1995, the U.S. has a better shape than Japan in their development of knowledge economy (Shibata, 2006). Following this reasoning, we argue that the importance of firm-specificity of asset is higher in Japan than in the U.S.

Combining the above argument where Japan has lower importance of managerial capability and higher importance of firm-specificity of asset compared with U.S., the predictions of our model point out to the same direction. That is, labor mobility was

[16] Also, Drucker (1993) for example, has argued that in the new economy, knowledge is not just another resource alongside the traditional factors of production—labor, capital, and land—but the only meaningful resource today.

lower, and specificity of asset and human capital was higher in Japan than in the U.S., especially in the catching up period.[17]

These predictions are consistent with empirical and observational evidence. Concerning labor mobility, it was found that the labor turnover rate was much higher in U.S. than in Japan (see Hashimoto and Raisian, 1985; Mincer and Higuchi, 1988). Hashimoto and Raisian (1985), for instance, found that the 15-year job retention rates of the male population between the early 1960s and the late 1970s were much higher in Japan than in the United States across all age groups. Concerning firm-specific human capital, Koike (1977, 1988) found, in his comparative analysis of Japanese and U.S. industrial relations, that Japanese workers acquired more firm-specific human capital through rotation among related jobs (see also Dertouzos, Lester and Solow, 1989; Ito, 1991). Concerning specificity of asset, we are unaware of direct observations or evidence. However, it is well known that Japanese firms conducted continuous process improvement more than U.S. firms did in the postwar growth period.[18] As argued by Morita (2001), if a firm conducts continuous process improvement, the technology is improved but a degree of specificity is introduced. This is because, in general, continuous process improvement involves a number of small changes and modifications, which lead to highly firm-specific technologies. This then suggests that specificity of asset was higher in Japanese firms than in the U.S. firms in the postwar growth period.

The Japanese economy has already caught up with the West, and most Japanese industries have got much closer to the world technology frontier. This increases the importance of managerial capability in which undertaking innovative activities now becomes crucially sensitive to higher managerial capability. Our model then predicts that the degree of the U.S.-Japanese differences become smaller. That is, labor mobility had increased, and specificity of asset and human capital has decreased in Japan. In reality, however, such transitions in Japan are likely to take place rather slowly due to vested interests and institutional inertia embedded in the Japanese economic system (Lincoln,

[17] In an alternative approach where promotion serves as a signal of the worker's ability, Owan (2004) shows that late-promotion practice which commonly observed in Japanese firms results in low turnover rate and long-term employment relationship; whereas early-promotion practice which is commonly observed in U.S. results in the opposite effects. Moreover, Chang and Wang (1995) explain the lower turnover rate and higher human capital accumulation in Japan than in the U.S. Their model is characterized by multiple equilibria and is analyzed in the framework where current employers have superior information on the abilities of their employees.

[18] See Morita (2001) for a review of evidence.

2001). Several empirical studies have been undertaken recently to find out whether or not the Japanese employment system has exhibited significant changes, but findings are not clear-cut thus far.[19]

6 Conclusion

We have developed a model of labor market competition that captures the link between capability of a firm's top management, specificity of a firm's asset, and firm-specificity of human capital. Firm-specificity of asset is a key concept in the RBV of the firm and TCE, and distinction between general and firm-specific human capital has played an important role in the human capital theory literature. We have contributed to these literatures by proposing a model in which the degree of firm-specificity is endogenously determined, where labor mobility generated by *ex ante* uncertainty of managerial capabilities and the link between firm-specificities of asset and human capital are the driving forces of the endogenous determination. Furthermore, our theoretical framework enriches a prediction of TCE on the relationship between uncertainty and governance structure by indicating that higher uncertainty can make vertical integration less likely. Given that the importance of managerial capability differs across industries, countries and time, our theoretical results yield empirical implications and predictions from a previously unexplored perspective.

[19]For example, Kambayashi and Kato (2017) study labor mobility and conduct cross-national analysis of micro data from Japan Employment Status Survey and U.S. Current Population Survey. They find that, on the one hand, core employees (age of 30-44 with at least five years of tenure) in Japan continued to enjoy much higher job stability than the U.S. counterparts consistently over the last twenty-five years. On the other hand, job stability for mid-career hires and youth employees deteriorated in Japan over the last twenty-five years, whereas there was no comparable decline in job stability in the U.S. counterparts.

Appendix

Proof of Lemma 1: Suppose that there exists a symmetric equilibrium in which both firms continue operation in period 2 and a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm at the beginning of period 2 whenever the realizations of managerial capability are different in both firms. First notice that in the Stage 3 subgame, firm i's second-period profit conditional on $a_i = x$ and $a_i \neq a_j$ is $\pi_i^E(z_i, n_i, z_j, n_j) = n_i(d + x + sz_i) + m_i^E(n_i, z_j, n_j)(d + x) - b(n_i + m_i^E(n_i, z_j, n_j))^2 - (n_i w_{i,2}^E(n_i, z_j, n_j) + m_i^E(n_i, z_j, n_j) w_{-i,2}^E(n_i, z_j, n_j))$ as analyzed in the text given $m_i^E(n_i, z_j, n_j) = \frac{1}{4b}[2x - sz_j - 2b(n_i - n_j)]$, $w_{-i,2}^E(n_i, z_j, n_j) = d + \frac{1}{2}sz_j - b(n_i + n_j) \geq \omega$ and $w_{i,2}^E(n_i, z_j, n_j) = d - \frac{1}{2}sz_j - b(n_i + n_j)$ is not binding, implying that

$$\begin{aligned} \pi_i^E(z_i, n_i, z_j, n_j) &= \frac{1}{16b}\{4\left[(b(n_i + n_j) + x)^2 + 4bsn_i z_i\right] \\ &\quad + 4s(3bn_i - bn_j - x)z_j + (sz_j)^2\}, \end{aligned} \tag{12}$$

The expression of the profit function $\pi_i^E(z_i, n_i, z_j, n_j)$ above changes if $w_{i,2}^E(n_i, z_j, n_j)$ is binding (firm i retained its worker using reservation wage), but the overall expected profit function at Stage 1 (see equation (8) in the text) does not change given the wage payment is cancelled out for the workers staying with their first-period employer in period 2.

Second notice that, if firm i contracts and firm j expands, the equilibrium size of of expansion/contraction can be solved analogously, which is $\frac{1}{4b}[-2x - sz_j - 2b(n_i - n_j)]$. This case can be ruled out since $-2x - sz_j - 2b(n_i - n_j) < 0$ for any symmetric equilibrium—a contradiction. Third, it cannot be the case that firm i retains only some of its period 1 employees and firm j ($j \neq i$) hires some workers from i in the equilibrium. The reason is as follows. Suppose firm i retains $n_i - l_i$ of its period 1 employees, where $l_i > 0$, and hire $r_i(> 0)$ workers from firm j in which the size of the expansion is $r_i - l_i$; firm j retains $n_j - r_j$ of its period 1 employees, where $r_j > 0$, and hire $l_j(> 0)$ workers from firm i in which the size of contraction is $r_j - l_j$. Then, firm i offers $d + x - 2b(n_i + r_i - l_i) \equiv w_{i,O}^E$ to hire r_i outside workers and firm j offers $d - x + sz_j - 2b(n_j - r_j + l_j) \equiv w_{j,R}^C$ to retain $n_j - r_j$ of its period 1 employees, in which $w_{i,O}^E = w_{j,R}^C$ and the size of expansion $r_i - l_i \equiv m_i$ equals that of contraction $r_j - l_j \equiv -m_j$ in equilibrium. We have $m_i = -m_j = \frac{1}{4b}[2x - sz_j - 2b(n_i - n_j)]$. Similarly, firm i offers

$d+x+sz_i-2b(n_i+r_i-l_i) \equiv w^E_{i,R}$ to retain n_i-l_i of its period 1 employees and firm j offers $d-x-2b(n_j-r_j+l_j) \equiv w^C_{j,O}$ to hire l_j outside workers, in which $w^E_{i,R}=w^C_{j,O}$ in equilibrium. The implied expansion/contraction size in equilibrium from this later case is $\frac{1}{4b}[2x+sz_i-2b(n_i-n_j)]$. Given that $\frac{1}{4b}[2x-sz_j-2b(n_i-n_j)] \neq \frac{1}{4b}[2x+sz_i-2b(n_i-n_j)]$ for any symmetric equilibrium, firm i (expansion firm) will retain all its period 1 employees.

Consider the Stage 3 subgame where $(a_i,a_j)=(-x,x)$. If firm i contracts and firm j expands in their firm sizes, firm i makes offer $w_{ii}=d-x+sz_i-2b(n_i+m_i)$ to retain its $n_i+m_i(m_i<0)$ workers from its period 1 employees where $d-x+sz_i-2b(n_i+m_i)$ is the expected productivity of firm i's first-period employees in i given n_i+m_i of them are retained. While firm j is willing to offer $d+x-2b(n_j+m_j)$ to hire $m_j(>0)$ new workers, where $d+x-2b(n_j+m_j)$ equals the expected productivity of firm i's first-period employees in firm j. In the equilibrium, both firms offer the same second-period wage to the workers in firm i such that $w_{ii}=w_{ji}$, and the number of workers from contraction equals that from expansion, $-m_i=m_j$. We obtain $m^C_i(z_i,n_i,n_j)=\frac{1}{4b}[2x-sz_i+2b(n_i-n_j)]$. Then, the equilibrium second-period wage for workers retained in firm i and newly hired in firm j becomes $d+\frac{1}{2}sz_j-b(n_i+n_j) \equiv w^C_{i,2}(z_i,n_i,n_j)$. Notice that, if firm i expands and firm j contracts in the equilibrium, the expansion/contraction size is $\frac{1}{4b}[-2x-sz_i+2b(n_i-n_j)]$. This equilibrium can be ruled out given $-2x-sz_i+2b(n_i-n_j)<0$ for any symmetric equilibrium—a contradiction. Further notice that, $0<m^C_i(z_i,n_i,n_j)<n_i$ holds in the equilibrium, which suggests $0<\frac{1}{4b}[2x-sz_i+2b(n_i-n_j)]<n_i$. This condition is the same as the condition (2) in the equilibrium. Lastly, notice that firm i will not hire some of firm j's workers while maintaining the contraction size, $m^C_i(z_i,n_i,n_j)$, in the equilibrium. Because this does not hold for symmetric equilibrium as analyzed in the previous paragraph. Then, firm i's second-period profit conditional on $a_i<a_j$ is $\pi^C_i(z_i,n_i,n_j)=(n_i-m^C_i(z_i,n_i,n_j))(d-x+sz_i)-b(n_i-m^C_i(z_i,n_i,n_j))^2-(n_i-m^C_i(z_i,n_i,n_j))w^C_{i,2}(z_i,n_i,n_j)$, implying that

$$\pi^C_i(z_i,n_i,n_j)=\frac{1}{16b}[2x-sz_i-2b(n_i+n_j)]^2. \tag{13}$$

Next consider the Stage 3 subgame where both firms have the same managerial capabilities, $a_i=a_j$. First note that it cannot be the case that one firm expands and the other contracts given that either $-sz_j+2b(n_i-n_j) \not> 0$ or $-sz_i+2b(n_j-n_i) \not> 0$ (the gap of realized managerial capability is now zero) under symmetric equilibrium. Then, both firms must stay unchanged in their firm sizes in the equilibrium. That is, each firm i will offer the wage to the extent that the expected productivity from the outside workers are the same at the level $d+a_i-2b(n_i+m_i)$ where $m_i=0$ holds in the equilibrium. That is, $w^S_{i,2}=w^S_{i,2}(n_i;a_i)=d+a_i-2bn_i$. Then firm i's second-period profit given $a_i=a_j$ and $w^S_{i,2}(n_i;a_i)$ is not binding is $\pi^S_i(z_i,n_i;a_i)=n_i(d+a_i+sz_i)-bn_i^2-n_iw^S_{i,2}(n_i;a_i)$, implying that

$$\pi^S_i(z_i,n_i;a_i)=n_i(sz_i+bn_i). \tag{14}$$

Note that, $w^S_{i,2}(n_i;a_i=-x)$ can be binding since $w^S_{i,2}(n_i;a_i=-x)=d-x-2bn_i<d-\frac{1}{2}sz_j-b(n_i+n_j)=w^E_{i,2}(n_i,z_j,n_j)$ in the equilibrium with positive turnover (i.e. $m^E_i(n^*,z^*,n^*)=\frac{1}{4b}(2x-sz^*)>0$). Again, whether or not $w^S_{i,2}(n_i;a_i=-x)$ is binding does not affect the expected overall profit function at Stage 1, as argued in the previous binding case where $a_i>a_j$ and firm i's retention wage is $w^E_{i,2}(n_i,z_j,n_j)$.

Hence, in the equilibrium where a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm in period 2, each firm i's expected profit in period 2 is $\pi_{i,2}(z_i,n_i,z_j,n_j)=\Pr(a_i>a_j)\pi^E_i(z_i,n_i,z_j,n_j)+\Pr(a_i<a_j)\pi^C_i(z_i,n_i,n_j)+\Pr(a_i=a_j)\pi^S_i(z_i,n_i;a_i)$, where $\Pr(a_i>a_j)=\Pr(a_i<a_j)=\Pr(a_i=a_j=x)=\Pr(a_i=a_j=-x)=\frac{1}{4}$.

Also, $w_{i,1}+E[w_{i,2}(z_i,n_i,z_j,n_j)]=2\omega$ holds for a worker employed by firm i in the equilibrium where $E[w_{i,2}(z_i,n_i,z_j,n_j)]=\Pr(a_i>a_j)w^E_{i,2}(n_i,z_j,n_j)+\Pr(a_i<a_j)w^C_{i,2}(z_i,n_i,n_j)+\Pr(a_i=a_j)w^S_{i,2}(n_i;a_i)$ and 2ω is the lifetime wage for individuals outside the industry. Note that $w^C_{i,2}(z_i,n_i,n_j)=w^E_{-j,2}(z_i,n_i,n_j)$ so that the second-period wage of the new workers who are hired by expansion firm is actually determined by contraction firm's strategic variables. By substituting the value of $w^E_{i,2}(z_i,n_i,z_j,n_j)$, $w^C_{i,2}(z_i,n_i,z_j,n_j)$, and $w^S_{i,2}(a_i,n_i)$, we obtain

$$E[w_{i,2}(z_i,n_i,z_j,n_j)]=d+\frac{1}{8}[s(z_i-z_j)-4b(3n_i+n_j)]. \tag{15}$$

Then, we find $w_{i,1}=w_{i,1}(z_i,n_i,z_j,n_j)$ where

$$w_{i,1}(z_i,n_i,z_j,n_j)=2\omega-d-\frac{1}{8}[s(z_i-z_j)-4b(3n_i+n_j)]. \tag{16}$$

Hence, each firm i's expected overall profit is $\Pi_i(z_i, n_i, z_j, n_j) = -\frac{1}{2}\theta z_i^2 - n_i w_{i,1}(z_i, n_i, z_j, n_j) + \pi_{i,2}(z_i, n_i, z_j, n_j)$, implying that

$$\begin{aligned}\Pi_i(z_i, n_i, z_j, n_j) \;&=\; \frac{1}{64b}\{\{-8b^2(7n_i^2 + 2n_i n_j - n_j^2) + 8x^2 - 4sx(z_i + z_j) \\ &\quad + s^2(z_i^2 + z_j^2) + 4b[sn_j(z_i - z_j) + n_i(16d - 32\omega + 15sz_i + sz_j) - 8\theta z_i^2]\},\end{aligned} \tag{17}$$

Let compute the partial derivatives of $\Pi(z_i, n_i, z_j, n_j)$. We find

$$\begin{aligned}(\partial/\partial z_i)\Pi_i(z_i, n_i, z_j, n_j) \;&=\; \frac{s}{32b}[2b(15n_i + n_j) - 2x + sz_i] - \theta z_i, \\ (\partial/\partial n_i)\Pi_i(z_i, n_i, z_j, n_j) \;&=\; d - 2\omega + \frac{1}{16}[15sz_i + sz_j - 4b(7n_i + n_j)].\end{aligned}$$

Given that $(z_i, n_i) = (z_j, n_j) = (z^*, n^*)$ in the symmetric equilibrium, the first-order conditions imply

$$\begin{cases} \left(\frac{s}{32b}\right)(sz^* - 2x) + (sn^* - \theta z^*) = 0 \\ d - 2\omega + sz^* - 2bn^* = 0 \end{cases}. \tag{18}$$

Solving the simultaneous equations, we obtain $z^* = \frac{16s(d-2\omega)-2xs}{32b\theta-17s^2}$ and $n^* = \frac{(d-2\omega)(32b\theta-s^2)-2xs^2}{2b(32b\theta-17s^2)}$ in the equilibrium.

Note that the profit function in equation (17) does not depend on whether $w_{i,2}^E(n_i, z_j, n_j)$ and $w_{i,2}^S(n_i; a_i = -x)$ are binding or not. But both $w_{i,2}^E(n_i, z_j, n_j)$ and $w_{i,2}^S(n_i; a_i = -x)$ should be equal to or greater than the reservation wage. Since $w_{i,2}^E(n_i, z_j, n_j) = d - \frac{1}{2}sz_j - b(n_i + n_j) > d - x - 2bn_i = w_{i,2}^S(n_i; a_i = -x)$ in the equilibrium with positive labor mobility, it requires that $d - \frac{1}{2}sz^* - 2bn^* \geq \omega$. Then, it implies $\omega \leq \frac{s^2(8d-x)}{32b\theta-s^2}$ is also necessary in characterizing equilibrium level of asset specificity and the equilibrium number of first-period workers (z^*, n^*). □

Proof of Lemma 2: We will establish the following claim.

Claim 1: In a symmetric equilibrium in which both firms continue operation in period 2 and a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm at the beginning of period 2 whenever the realizations of managerial capability are different, condition $32b\theta - 17s^2 > 0$ is necessary for each firm i's optimal choice $(z_i, n_i) = (z^*, n^*)$.

Proof of Claim 1: First, let us check the second-order condition of firm i's profit maximization problem for the necessary parameterization. We have $(\partial^2/\partial z_i^2)\Pi_i(z_i, n_i, z_j, n_j) = \frac{s^2}{32b} - \theta$, $(\partial^2/\partial n_i^2)\Pi_i(z_i, n_i, z_j, n_j) = -\frac{7}{4}b$, and $(\partial^2/\partial z_i \partial n_i)\Pi_i(z_i, n_i, z_j, n_j) = (\partial^2/\partial n_i \partial z_i)$ $\Pi_i(z_i, n_i, z_j, n_j) = \frac{15}{16}s$. Hence, the first-order leading principal minor of $D^2\Pi_i(z_i, n_i, z_j, n_j)$ is negative and the second-order leading principal minor of $D^2\Pi_i(z_i, n_i, z_j, n_j)$ is $\frac{1}{256}(448b\theta - 239s^2)$. That is, $D^2\Pi_i(z_i, n_i, z^*, n^*)$ is negative definite if $448b\theta - 239s^2 > 0$. Since $448b\theta - 239s^2 > 0 \Rightarrow 32b\theta - 17.1s^2 > 0$, $32b\theta - 17s^2 > 0$ is implied by the second-order condition of firm i's profit maximization problem. $\square$

Condition (2) holds if a symmetric equilibrium in which both firms continue operation in period 2 and a strictly positive number of workers leave the low-capability firm and all of them move to the high-capability firm at the beginning of period 2 whenever the realizations of managerial capability are different. By plugging $(z^*, n^*) = (\frac{16s(d-2\omega)-2sx}{32b\theta-17s^2}, \frac{(32b\theta-s^2)(d-2\omega)-2s^2x}{2(32b\theta-17s^2)})$, we have $0 < \frac{1}{4b}(2x - sz^*) < \frac{(d-2\omega)(32b\theta-s^2)-2xs^2}{2b(32b\theta-17s^2)} \Rightarrow 0 < \frac{16xb\theta-4s^2(d-2\omega+2x)}{b(32b\theta-17s^2)} < \frac{(d-2\omega)(32b\theta-s^2)-2xs^2}{2b(32b\theta-17s^2)}$. From Claim 1 and the condition $0 < \frac{16xb\theta-4s^2(d-2\omega+2x)}{b(32b\theta-17s^2)}$, we obtain $x > \frac{s^2(d-2\omega)}{2(2b\theta-s^2)}$. Also, from Claim 1 and the condition $\frac{16xb\theta-4s^2(d-2\omega+2x)}{b(32b\theta-17s^2)} < \frac{(d-2\omega)(32b\theta-s^2)-2xs^2}{2b(32b\theta-17s^2)}$, we obtain $x < \frac{(d-2\omega)(32b\theta+7s^2)}{32b\theta-14s^2}$. Note that $\frac{s^2(d-2\omega)}{2(2b\theta-s^2)} > 0$ if $d - 2\omega > 0$. Further note that $\frac{s^2(d-2\omega)}{2(2b\theta-s^2)} < \frac{(d-2\omega)(32b\theta+7s^2)}{32b\theta-14s^2}$ given Claim 1 and $d - 2\omega > 0$. That is, let $0 < \underline{x} = \frac{s^2(d-2\omega)}{2(2b\theta-s^2)}$ and $\bar{x} = \frac{(d-2\omega)(32b\theta+7s^2)}{32b\theta-14s^2}$, the range of x satisfying $x \in (\underline{x}, \bar{x})$ is non-empty. Final notice that, by using $\omega \leq \frac{s^2(8d-x)}{32b\theta-s^2}$, it only changes the range of the upper and lower bounds of x while the non-empty set of x still exists. This implies the result of Lemma 2. $\square$

Proof of Proposition 1:

Claim 1, Lemma 1 and 2, along with the analysis presented in the text, imply the following necessary part of the proposition: "Suppose that there exists a unique symmetric equilibrium in which a strictly positive number of workers leave low-capability firm and all of them move to high-capability firm whenever the realizations of both firms' managerial capabilities are different in period 2. Then $x \in (\underline{x}, \bar{x})$, where $0 < \underline{x} < \bar{x}$, must hold." We now check sufficiency. Suppose that $0 < \underline{x} < \bar{x}$ holds, and that each firm i chooses $(z_i, n_i) = (z^*, n^*) = \left(\frac{16s(d-2\omega)-2sx}{32b\theta-17s^2}, \frac{(32b\theta-s^2)(d-2\omega)-2s^2x}{2(32b\theta-17s^2)}\right)$ where $\omega \leq \frac{s^2(8d-x)}{32b\theta-s^2}$.

First note that $z^* \geq 0$ and $n^* \geq 0$ hold given $0 < \underline{x} < x \leq \bar{x}$. Also, each firm i is willing to hire workers since $d > 2\omega$. Then, following the procedure in the text and the proof in Lemma 1, firm i's optimal decision in period 2 is to expand in its firm size by offering $w^E_{-i,2}(n_i, z_j, n_j)$ to $m^E_i(n_i, z_j, n_j)$ new workers from firm j and $w^E_{i,2}(n_i, z_j, n_j)$ to all its period 1 employees if $(a_i, a_j) = (x, -x)$, to contract in its firm size by offering $w^C_{i,2}(z_i, n_i, n_j)$ to retain $n_i - m^C_i(z_i, n_i, n_j)$ of its period 1 employees if $(a_i, a_j) = (-x, +x)$, and to stay unchanged in its firm size by offering $w^S_{i,2}(n_i; a_i)$ if $a_i = a_j$. This is the case if the condition (2) $(0 < \frac{1}{4b}[2x - sz_j - 2b(n_i - n_j)] < n_j)$ holds, suggesting each firm i's expected overall profit at Stage 1 is $\Pi_i(z_i, n_i, z_j, n_j)$. Notice that, $0 < \frac{1}{4b}[2x - sz_j - 2b(n_i - n_j)] < n_j$ holds true for $(z_i, n_i) = (z_j, n_j) = (z^*, n^*)$.

That is, if $0 < \underline{x} < x \leq \bar{x}$, there exists a symmetric equilibrium with the following properties: (i) $(z_i, n_i) = (z^*, n^*) = \left(\frac{16s(d-2\omega)-2sx}{32b\theta-17s^2}, \frac{(32b\theta-s^2)(d-2\omega)-2s^2x}{2(32b\theta-17s^2)}\right)$ where $z^* \geq 0$ and $n^* \geq 0$ where $\omega \leq \frac{s^2(8d-x)}{32b\theta-s^2}$; (ii) at Stage 1, each firm chooses the level of asset specificity z^* and makes first-period wage offer w^*_1 to employs n^* workers; (iii) at Stage 3, all period 1 employees stay in the industry for all realizations of (a_i, a_j); if both firms have different managerial capabilities, firm i who receives higher managerial capability retains all its first-period employees at wage w^{Retain}_2 and expands in its firm size by hiring m^* workers from firm j $(j \neq i)$ at wage w^{Switch}_2, whereas firm j contracts in its firm size and retains $n^* - m^*$ workers at second-period wage w^{Switch}_2; if $a_i = a_j$, each firm i retains all its first-period workers at the second-period wage $w^S_{i,2}(n^*; a_i)$ and stays unchanged in its firm size; (iv) no worker leaves the industry in period 2 and the second-period wage w^{Retain}_2 for expansion firm's period 1 employees or $w^S_{i,2}(n^*; a_i = -x)$ might be binding (equal to ω), and the expected number of workers who switch their employers at the beginning of period 2 is m^* conditional on both firms have different managerial capabilities.

Finally, if $0 < \underline{x} < \bar{x}$, the symmetric equilibrium described in the previous paragraph is also unique. Because the condition in Claim 1 $(32b\theta - 17s^2 > 0)$ ensures that $\Pi_i(z_i, n_i, z_j, n_j)$ is globally concave over all $z_i > 0$ and $n_i > 0$, and the only solution satisfying both $(\partial/\partial z_i)\Pi_i(z_i, n_i, z_j, n_j) = 0$ and $(\partial/\partial n_i)\Pi_i(z_i, n_i, z_j, n_j) = 0$ for each firm $i$is $(z_i, n_i) = (z^*, n^*)$. This completes the proof of the proposition. $\square$

Proof of Proposition 2 and 3:

(i) Note $z^* = \frac{16s(d-2\omega)-2xs}{32b\theta-17s^2}$, we find $\frac{\partial z^*}{\partial x} = \frac{-2s}{32b\theta-17s^2} < 0$ given $32b\theta - 17s^2 > 0$. Also, $\frac{\partial z^*}{\partial s} = \frac{[16(d-2\omega)-2x](32b\theta-17s^2)+[16s(d-2\omega)-2xs](34s)}{(32b\theta-17s^2)^2} > 0$ given $16s(d-2\omega) - 2xs > 0$ and $32b\theta - 17s^2 > 0$.

(ii) Note $n^* = \frac{(d-2\omega)(32b\theta-s^2)-2xs^2}{2b(32b\theta-17s^2)}$, we find $\frac{\partial n^*}{\partial x} = \frac{-2s^2}{2b(32b\theta-17s^2)} < 0$. Also, $\frac{\partial n^*}{\partial s} = \frac{32s[4(d-2\omega)-x]}{(32b\theta-17s^2)^2} > 0$ given $16s(d-2\omega) - 2xs > 0$.

(iii) Note $m^* = \frac{1}{4b}(2x - sz^*)$, we find $\frac{\partial m^*}{\partial x} = \frac{1}{4b}(2 - s\frac{\partial z^*}{\partial x}) > 0$ given $\frac{\partial z^*}{\partial x} < 0$. Then given $\frac{\partial n^*}{\partial x} < 0$ and $\frac{\partial m^*}{\partial x} > 0$, we find $\partial(\frac{1}{4}\frac{2m^*}{n^*})/\partial x = \frac{1}{(2n^*)^2}[\frac{\partial m^*}{\partial x}(2n^*) - m^*(\frac{\partial n^*}{\partial x})] > 0$. Also, we find $\frac{\partial m^*}{\partial s} = -\frac{1}{4b}\left(z^* + s\frac{\partial z^*}{\partial s}\right) < 0$ given $z^* \geq 0$ and $\frac{\partial z^*}{\partial s} > 0$. Then given $\frac{\partial n^*}{\partial s} > 0$ and $\frac{\partial m^*}{\partial s} < 0$, we find $\partial(\frac{1}{4}\frac{2m^*}{n^*})/\partial s = \frac{1}{(2n^*)^2}[\frac{\partial m^*}{\partial s}(2n^*) - m^*(\frac{\partial 2n^*}{\partial s})] < 0$. $\square$

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