Wage Contracts and Specific Human Capital Investment Under Uncertainty

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I. Introduction

The main task of this paper is to investigate the effect of uncertainty about a worker's productivity on his specific human capital (SHC) investment. Related to this are the questions: At each different level of productivity uncertainty what wage must a firm offer to induce from a worker the investment in SHC that maximizes its expected profit? How is the stability of a given employment relationship affected by productivity uncertainty?

This investigation is inspired by a comparison of industrial relations in Japan with those in the United States. We observe that in Japanese firms the employment relationship is typically more stable than in U.S. firms. Japanese workers are also more devoted to their employers and cooperate better with fellow workers in the workplace. We see this greater devotion and better workplace cooperation as evidence of the Japanese worker's heavier investment in SHC than his American counterpart's. We believe that this difference in SHC investment has contributed greatly to recent changes in the two countries' relative competitive powers and industrial strengths. A question many are eager to ask and find an answer to is then: Why does the Japanese worker invest more in SHC than his American counterpart?

It is tempting to say that the difference is attributable to the fact that job tenure is longer in Japan than in the United States. The longer an employment relationship lasts, the longer the involved parties can reap returns from this relationship in which they have invested. The expectation of a more stable employment relationship, therefore, provides incentives for more investment in the relationship. This relationship between SHC investment behavior and job turnover has been discussed by many, (e.g., Becker, p.21-2). But the question then becomes: What determines the expected length of job tenure? SHC theory holds that investment in SHC is itself an important factor affecting the stability of an employment relationship.[1] It thus appears that there may be causal links in

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[1]. "Employees with specific training have less incentive to quit, and firms have less incentive to fire them, than employees with no training or general training, which implies that quit and layoff rates are inversely related to the amount of specific training." (Becker, p.24)

Japanese firms are likely to have faced less uncertainty in worker productivity than American firms. The question now becomes whether this difference in productivity uncertainty can explain heavier SHC investment by workers and a more stable employment relationship in Japan than in the United States.

This paper shows that it can. Using a wage contract model, we are able to establish that employment stability, worker investment in SHC, and wage levels all depend on the level of productivity uncertainty. Everything else equal, greater productivity uncertainty leads to a less stable employment relationship, less investment in SHC by workers, and also a lower wage. The implication for performance is that, on average, a worker is less productive when there is greater uncertainty. We believe that it is the first time that it has shown how three closely related variables - a worker's wage level, his SHC investment, and his probability of separation from an employer - are endogenously and simultaneously determined by the worker's productivity uncertainty. Our results can explain the differences in SHC investment behavior and industrial relations not only between Japan and the United States, but also across different industries in a single economy. Furthermore, we believe that they also have some policy implications. For example, in order to provide incentives for SHC investment and thereby raise worker productivity (again in average terms), it may be desirable to use public policy to reduce productivity uncertainty.

In our model, a firm offers a worker a contract consisting of a wage level and a clause that either party may sever the relationship as he wishes without penalty. After accepting the contract, the worker invests in SHC. The firm cannot observe the level of SHC investment, but after SHC investment is made, it can observe the realization of the worker's productivity. This productivity is not observable by the worker.

The intuition behind our results is the following. If the wage offer is higher than the reservation wage, the worker will want to stay in the firm as long as possible. Now, while his productivity stays above the wage level, the firm will not initiate separation. Therefore the worker will try to enhance his productivity, and hence prolong his job tenure, by making SHC investment. Because

payments.

If the worker accepts the offer, he makes an investment in SHC at the beginning of the second stage. The amount of this investment by the worker is not observable to the firm. After that, the worker's productivity, i.e., the actual θ, is revealed, but only to the firm, not to the worker. Thus there is two-sided information asymmetry (IAS).

(IAS) Only the worker knows the amount of his investment in SHC; only the firm can observe the actual value of θ.

(IAS) makes renegotiation of the contract impossible. Also we assume that

(A2) There is limited liability on the part of the worker.

The content of the contract is a wage offer, w_o, from the firm to the worker, subject to the condition that production is carried out in the second stage, or in other words, that separation does not happen. Because of (A2) the worker's reservation wage $\underline{w}$ and the firm's wage offer to the worker w_o must satisfy

$$w_o \geq \underline{w} .$$

After the worker's investment and the revelation of his actual productivity to the firm, the firm and the worker then decide whether they should separate or carry out the production. If production is carried out, the worker will receive w_o, which the firm offered in the contract. If separation happens, the worker will receive nothing from the firm, but he can get his reservation wage, $\underline{w}$, from the market.

Separation happens if either party wants it to, but the worker will never initiate separation because, in the second stage, his investment in SHC is already sunk. The relevant comparison for him is thus between leaving the firm and receiving his reservation wage $\underline{w}$, or staying and receiving w_o offered by the firm. Because $\underline{w} \leq w_o$, the latter is his only rational choice. So, in effect, the firm is the only party who will ever want separation to happen. The firm will initiate separation if the worker's actual productivity turns out to be lower than the wage he will receive from the firm, w_o. In such a case, the firm will initiate separation to avoid a loss. We call this the "separation condition", or

(SC) $\theta - w_o < 0$.

$$I(\theta \geq w_o) = \begin{cases} 1, \text{ if } \theta \geq w_o; \\ 0, \text{ otherwise.} \end{cases}$$

III. Uncertainty, the Wage Offer, and SHC Investment

We investigate the relationships among the worker's investment level c, the firm's wage offer w_o, the probability of separation s, and productivity uncertainty σ by solving the optimization problems laid out in Section II.

When the firm in the first period offers a wage to the worker, it knows that the worker will determine his investment in SHC accordingly. More specifically, it knows from the worker's (IMC) that the relationship between the wage offer w_o and the worker's optimal level of investment must satisfy Proposition 1 below.

Proposition 1: Under (A1) through (A4), the worker's optimal investment c^* is a function of w_o satisfying

$$(IMC)' \quad (K\alpha c^{\alpha-1}/\sigma)\, f[(w_o - Kc^\alpha)/\sigma] = 1/(w_o - \underline{w})$$

Proof: Let $E(w) = w_o - (w_o - \underline{w})s - c \equiv g(c)$. Then

$$g'(c) = -(w_o - \underline{w})(ds/dc) - 1 .$$

But

$$\frac{ds}{dc} = \frac{d}{dc}\int_{-\infty}^{w_o} \sigma^{-1} f[(x - Kc^\alpha)/\sigma]dx$$

$$= -K\alpha\sigma^{-2}c^{\alpha-1} \int_{-\infty}^{w_o} f'[(x - Kc^\alpha)/\sigma]dx$$

$$= -K\alpha\sigma^{-1}c^{\alpha-1} f[(x - Kc^\alpha)/\sigma] \Big|_{x=-\infty}^{x=w_o}$$

$$= -K\alpha\sigma^{-1}c^{\alpha-1} f[(w_o - Kc^\alpha)/\sigma]$$

Therefore,

$$g'(c) = (w_o - \underline{w})K\alpha\sigma^{-1}c^{\alpha-1} f[(w_o - Kc^\alpha)/\sigma] - 1$$

Because $\alpha < 1/2$, we have

$$g'(0) = \lim_{c\to 0} g'(c) = \infty, \text{ and } g'(\infty) = \lim_{c\to\infty} g'(c) = -1.$$

These two limits imply that g(c) has a maximal point and the maximal point satisfies

w_o has two effects on the worker's investment decision. First, a higher w_o means a higher benefit from any given reduction in the probability of separation s, i.e., $(w_o - \underline{w})$ is higher. Call this the rent effect. It always encourages more investment by the worker. Second, changing w_o also affects the worker's ability at the margin to influence the separation probability s through SHC investment. Call this the separation effect. Figure 2 illustrates this effect. In the figure, $\delta = \Delta(Kc^\alpha)$. The shaded area is the change in the probability of separation, $-\Delta s$, that is caused by a marginal change in SHC, that is the separation effect. From the figure, it is quite clear that when $w_o < Kc^\alpha$, moving w_o to the right increases the shaded area, i.e., a higher w_o means c is marginally more effective in reducing s. It then works in favor of more investment. When $w_o > Kc^\alpha$, the opposite is true: moving w_o to the right decreases the shaded area, i.e., a higher w_o means that c is marginally less effective in reducing s. Hence the separation effect works to reduce incentives for investing in c when w_o is higher. In summary, if $w_o < Kc^\alpha$, the rent effect and the separation effect both work in the favorable direction, and they jointly induce higher SHC investment; If $w_o > Kc^\alpha$, the two effects act in opposite directions, and the net effect of a higher wage w_o on SHC investment c is thus ambiguous.

Now we look at the effect of productivity uncertainty σ on the worker's optimal investment in SHC with a given w_o

In Figure 3, the two density functions correspond to variances σ_1^2 and σ_2^2 respectively with $\sigma_2 > \sigma_1$. The single-shaded area is the marginal change in the probability of separation caused by an increase in SHC when θ has standard deviation σ_2. The whole shaded area is the one that corresponds to σ_1. From the graph, one can see that when w_o is close enough to Kc^α, which is the average productivity, the marginal benefit of SHC investment is larger for smaller uncertainty, and when w_o is not so close to Kc^α, the opposite is true. Indeed, straightforward calculation from (IMC)' yields

$$\frac{dc^*}{d\sigma} = - \frac{[K\alpha(w_o-\underline{w})]^{-1} + c^{\alpha-1}\sigma^{-2}(w_o-Kc^\alpha)f'[\sigma^{-1}(w_o-Kc^\alpha)]}{(1-\alpha)c^{\alpha-2}f[\sigma^{-1}(w_o-Kc^\alpha)] + K\alpha\sigma^{-1}c^{2\alpha-2}f'[\sigma^{-1}(w_o-Kc^\alpha)]}$$

Clearly, as $w_o \to \infty$, $E(\pi) \to -\infty$. So if $w_o^* > \underline{w}$, it must satisfy the first order condition. ■

Intuitively, the probability of operation, 1 - s, is the marginal cost of raising the wage offer, and $(1-s)[d(Kc^\alpha)/dw_o] = (1-s)K\alpha c^{\alpha-1}(dc/dw_o)$ is the marginal benefit of raising the wage offer. In equilibrium, the marginal cost equals the marginal benefit, i.e.,

$$K\alpha c^{\alpha-1}(dc/dw_o) = 1.$$

Having determined the optimal wage offer of the firm, we want to find out about the relationship between the optimal SHC investment and the optimal wage offer.

Proposition 4: Under (A1) through (A5), the optimal SHC investment c and the optimal wage offer w_o have the relationship[3]

$$Kc^\alpha = [(1 - \alpha)/\alpha](w_o - \underline{w}) .$$

Proof: According to Proposition 3, in equilibrium, c and w_o have the relationship

$$K\alpha c^{\alpha-1}(dc/dw_o) = 1.$$

Substituting (dc/dw_o) given in the proof of Proposition 2 into this expression yields

$$K\alpha c^{\alpha-1}(dc^*/dw_o)$$

$$= \frac{K\alpha c^{\alpha-1}[(w_o-\underline{w})^{-2} + K\alpha\sigma^{-2}c^{\alpha-1}f'[\sigma^{-1}(w_o-Kc^\alpha)]}{K^2\alpha^2\sigma^{-2}c^{2\alpha-2}f'[\sigma^{-1}(w_o-Kc^\alpha)] + K\alpha(1-\alpha)\sigma^{-1}c^{\alpha-2}f[\sigma^{-1}(w_o-Kc^\alpha)]}$$

$$= \frac{K\alpha c^{\alpha-1}(w_o-\underline{w})^{-2} + K^2\alpha^2\sigma^{-2}c^{2\alpha-2}f'[\sigma^{-1}(w_o-Kc^\alpha)]}{K^2\alpha^2\sigma^{-2}c^{2\alpha-2}f'[\sigma^{-1}(w_o-Kc^\alpha)] + K\alpha(1-\alpha)\sigma^{-1}c^{\alpha-2}f[\sigma^{-1}(w_o-Kc^\alpha)]}$$

$$= 1 .$$

Rearranging and canceling terms leads to

$$(1 - \alpha)\sigma^{-1}c^{-1} f[(w_o - Kc^\alpha)/\sigma] = (w_o - \underline{w})^{-2} .$$

But Proposition 1 says that

$$f[(w_o - Kc^\alpha)/\sigma] = [(w_o - \underline{w})K\alpha]^{-1}\sigma c^{1-\alpha} .$$

Combining the above two equations and rearranging yields the result. ■

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[3] For notational simplicity, we omit the superscript "*" denoting optimal c and w_o from this point on.

have the same sign, where f is the density function and

$$y \equiv [(2 - (1/\alpha))w_o + ((1/\alpha) - 1)\underline{w}]/\sigma = (w_o - Kc^{\alpha})\sigma^{-1}.$$

Proof: By Proposition 4,

B. $Kc^{\alpha} = [(1 - \alpha)/\alpha](w_o - \underline{w})$.

Rearranging, we have

B.' $y = [(2 - (1/\alpha))w_o + ((1/\alpha) - 1)\underline{w}]/\sigma = (w_o - Kc^{\alpha})\sigma^{-1}$.

Differentiating both sides of B with respect to σ,

$$K\alpha c^{\alpha-1}[(dc/dw_o)(dw_o/d\sigma) + dc/d\sigma] = [(1-\alpha)/\alpha](dw_o/d\sigma).$$

The first term in the brackets on the left hand side, $(dc/dw_o)(dw_o/d\sigma)$, is the indirect effect of σ on c through w_o, and the second term, $dc/d\sigma$, is the direct effect of σ on c. The sum of the two terms is the total effect of σ on c. By Proposition 3,

$$K\alpha c^{\alpha-1}(dc/dw_o) = 1.$$

Substituting and rearranging, we have

$$K\alpha c^{\alpha-1}(dc/d\sigma) = [(1-2\alpha)/\alpha](dw_o/d\sigma).$$

where $(1-2\alpha)/\alpha > 0$. Therefore, $dw_o/d\sigma$ has the same sign as $dc/d\sigma$, which is given before Proposition 3. By Lemma A, the denominator of $dc/d\sigma$ is positive. Rewrite (IMC)' in Proposition 1 as

C. $K\alpha\sigma^{-1}c^{\alpha-1}f(y) = (w_o - \underline{w})^{-1}$.

By substituting C into the numerator of $dc/d\sigma$, it is easy to see that the numerator of $dc/d\sigma$, thus $dc/d\sigma$ itself and $dw_o/d\sigma$, have the same sign as $-[f(y) + yf'(y)]$.■

In the proof, it was shown that both the effect of σ on the optimal wage w_o and thus, by Proposition 4, the total effect of σ on SHC investment c have the same sign as the direct effect of σ on c, provided that $\alpha < 1/2$.

This proposition tells us that if $[f(y) + yf'(y)] > 0$, the optimal wage offer w_o and the worker's productivity uncertainty σ will have a negative relationship, which by Proposition 4 implies a negative relationship between the worker's optimal SHC investment c and productivity uncertainty. Now the question is reduced to what the sign of $[f(y) + yf'(y)]$ is. As discussed before, the answer depends on the shape of the distribution of the productivity as well as the

parameterization of symmetric distributions with finite support; as the parameter changes, the family of beta density functions provides a large variety of bell-type shapes with different tail properties. Let

$$f(y)=\begin{cases} b(p)[(2p+1)^{1/2}+y]^{p-1}[(2p+1)^{1/2}-y]^{p-1}, & \text{if } -(2p+1)^{1/2}<y<(2p+1)^{1/2} \\ 0, \text{ otherwise.} \end{cases}$$

where $b(p) = [2(2p+1)^{1/2}]^{1-2p}[\Gamma(2p)/\Gamma(p)\Gamma(p)]$. Γ in $b(p)$ is the gamma function, and p in $f(y)$ satisfies $p > 2$. f is the density function of a standardized symmetric beta distribution satisfying

$$\int_{-\infty}^{\infty} xf(x)dx = 0,$$

$$\int_{-\infty}^{\infty} x^2f(x)dx = 1, \text{ and}$$

$$f'(x) \leq 0 \text{ for } x > 0.$$

Straightforward calculation yields

$$(*)f(y) + yf'(y)=\begin{cases} f(y)\dfrac{(2p+1) - (2p-1)y^2}{(2p+1) - y^2}, & \text{if } -(2p+1)^{1/2} < y <(2p+1)^{1/2}; \\ 0, & \text{otherwise.} \end{cases}$$

Because $f(y) > 0$ when $-(2p+1)^{1/2} < y <(2p+1)^{1/2}$, we know that $f(y) + yf'(y)$ and $[(2p + 1) - (2p - 1)y^2]$ have the same sign. Given the value of p, the sign of $[(2p + 1) - (2p - 1)y^2]$ depends on the value of y. But y is determined in Proposition 5 by the optimal wage offer w_o. A general observation is that, as can be seen from Equation (*), $f(y) + yf'(y) > 0$ is more likely to be true when the parameter p in the beta distribution is smaller. In terms of the shape of the density function, a smaller p implies a flatter distribution.[4]

In the previous section, we found that a sufficient condition for $dw_o/d\sigma$ to be negative was for σ to be large enough. However, we did not give a numerical expression for the critical value of σ. Further, values of σ are not always easy to observe. Because of these problems, we would find it hard to determine in

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[4] In fact, we can show that $(dw_o/d\sigma) < 0$ is true for all σ for the family of uniform distributions. The uniform distribution is a special case of beta distribution with $p = 1$. When $p = 1$, we have $f(y)+yf'(y) = 1 > 0$. It should be pointed out, however, that the case of the uniform distributions is different from our general presentation in that the density function of a uniform distribution is not smooth on the interval $(-\infty,\infty)$.

employment relationships are typically much less stable than this. Interested readers may refer to Section VII, where some separation data are given that compare employment stability in Japan with that in the United States. A direct, strict and accurate comparison of real world data with the separation probability value s_o is not valid, for ours is a static and partial equilibrium model that omits many complicated and dynamic factors. But a s_o many times smaller than the real world separation probability indicated by the data can only lend support to the speculation that most firms in the real world have separation probabilities s greater than s_o. The same can be said about s being smaller than $1-s_o$

V. Uncertainty and Employment Stability

We now turn to discuss the impact of productivity uncertainty σ on employment stability (1 - s). Suppose that at a higher level of uncertainty, the firm offers the worker a lower wage. A lower wage has two effects on employment stability. Its direct effect is to lower the probability of separation, s. But the worker will respond to a lower wage by investing less in SHC and thereby moving the expected productivity to the left. This has an indirect effect of increasing the probability of separation. The net effect of greater productivity uncertainty on employment stability is hence not automatically clear. A third factor, that as the uncertainty increases, the tail of the distribution becomes longer, further complicates the matter. But it turns out that the following relationship exists between uncertainty and employment stability.

Proposition 8: In equilibrium, if $Kc^{\alpha} > \underline{w}$, then the probability of separation increases as productivity uncertainty increases, i.e., $(ds/d\sigma)>0$. $Kc^{\alpha} > \underline{w}$ is also a necessary condition for $(ds/d\sigma)>0$ to be true.

Corollary B: Everything else given, $Kc^{\alpha} > \underline{w}$ when K is large enough.

Intuitively, because of the assumption that $\alpha < 1/2$, the change in Kc^{α} due to changes in K and σ is larger than the corresponding change in the optimal wage w_o, as is discussed after Proposition 4. Two results follow. One is that, as K increases, both Kc^{α} and w_o increase due to higher returns to the investment, and Kc^{α} increases faster than and will eventually be greater than the optimal wage

come up mostly with their own fresh innovations while the followers can always duplicate managerial methods and technology from the leaders. Historically, this is indeed the case for the American and Japanese economies. As a catchup economy, Japan duplicated managerial methods and technology from mature economies, while the Unites States continued to invest in research and development of new technologies. This phenomenon worked to increase the risk and uncertainty that American firms faced and reduce the risk and uncertainty that Japanese firms faced.[6] Denison and Chung describe how Japanese firms duplicated American practices.

> Japanese business has sought to duplicate production conditions, including the use of capital, of efficient Western firms, particularly those in the United States. The effort to raise output per worker by adopting American practices, including the amount of capital used per worker, appears to have been pursued more consciously and energetically than in other countries. The ratio of capital input to labor input in the nonresidential

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[6] Kanter (1986) discusses four requirements to be met in innovation. The essence of these requirements is that firms engaged in innovation face the risks and uncertainties. First, there is uncertainty in terms of the time and resources involved. "The innovation process involves little or no precedent or experience base to use to make forecasts about results. Hoped-for timetables may prove unrealistic. Anticipated costs may be overrun. Results are highly uncertain." (p.12).

Second, there is uncertainty associated with labor turnover and knowledge loss. "The knowledge that resides in the participants in the innovation effort is not always codified or codifiable. Efforts are very vulnerable to turnover, because of the loss of this knowledge and experience." (p.13).

Third, there is uncertainty about alternatives. "In the innovation process, there is always competition with alternative courses of action. (The pursuit of the air-cooled engine at Honda Motor, for example, drew time and resources away from improving the water-cooled engine [Sakiya 1982].) Furthermore, sometimes the very existence of a potential innovation poses a threat to vested interests - whether the interest is that of a salesperson receiving high commissions on current products or of the advocates of a competing direction. Indeed, observers point to "political" problems as one of the major causes for the failure of corporate entrepreneurship (Fast 1976)." (p.13-4).

Finally, there is a "boundary" crossing problem."The innovation process is rarely if ever contained solely within one unit. ...many of the best ideas are interdisciplinary or interfunctional in origin ...[innovations] inevitably send out ripples and reverberations to other organizational units, whose behavior may be required to change in light of the needs of innovations ...there may be the need to generate unexpected innovations in another domain in order to support the primary product, like the need to design a new motor to make the first Apple computer viable." (p.15).

at an annual rate of 19.6 percent. Included in this industry are products like automobiles and home electronics. Denision and Chung describe the strong market demands for these two products that contributed to their accelerated rates of growth.

> Passenger car production in Japan grew more than 155-fold from 1955 to 1970, truck production 46-fold, and bus production about 9-fold. Since 1967 Japan has ranked as the second largest producer in the world, second only to the United States. In 1972 annual production exceeded 4 million passenger cars, more than one-seventh of total world production.[8]
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> ...Equipping a nation of 100 million with household appliances for the first time, when accomplished in two decades or less, creates a huge market. This happened in Japan. In the mid-1950s, hardly anyone owned electric cleaners, electric washers, electric refrigerators, or television sets; in the 1970s, nearly everyone did. The speed with which domestic markets for these products moved from original equipment toward dependence on replacement is indicated by the fact that from 1964 to 1971 alone the percentage of households with electric washers jumped from 61 to 94, with electric refrigerators from 38 to 91 by the mid-1960s. ...Growth of transistor radios, cameras, and sewing machines, and watches was no less outstanding. (p.76).

Strong demand for a key industrial product and consequently the rapid growth of the industry in turn creates a large market for the products of a number of supporting industries.

> Since the machinery industries are large users of steel, and such other steel-using industries as construction were also booming, swiftly rising demand for steel was assured.(Denison and Chung, p.77).

One may also note that a strong demand for automobiles will lead to a strong

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[8] Odaka, Ono and Adachi (1988, p.42-9) further explain the causes of such a strong demand. It started with a massive demand for trucks generated by the Korean War. From 1955 on, income increases began to accelerate. Income more than doubled between 1960 to 1970. Cost reductions also played a role, although a much less significant one compared with that of income increases. They also noted how the oil shocks in the 1970s boosted international demand for small and fuel efficient Japanese cars.

to measure in general, but also in real life the distinction between general and SHC is rarely clear cut.[10] Consequently, comparative studies of international differences in SHC investments have been rare. In spite of all these difficulties in making comparisons, however, casual observations do provide good reasons for us to believe that the Japanese worker invests more heavily in SHC than his American counterpart, as explained below.

First, we may infer SHC investment from job tenure. As mentioned in the Introduction, SHC theory holds that job tenure and the amount of SHC are two closely related variables. Because SHC is not directly measurable, in empirical studies, it is a common practice to use job tenure as a proxy.[11] For this reason, a much lower job turnover rate in Japan than in the United States would suggest heavier SHC investment in Japan. According to Evans (p.78), 1965 data show that one-year job mobility for all age groups was twice as high in the United States as in Japan for male workers. (9.9 and 4.7 percent, respectively.) For younger age groups, the ratios were even higher. Evans also reported that

> In 1969 the U.S. rates of job accessions and separations were 4.7 and 4.9 per 100, respectively. These were about double the Japanese rates of 2.6 and 2.4 per 100 employees. ...The 10-year job stability rates for males aged 30 to 40 in Japan are significantly higher than those for American males ages 25-44. Taking manufacturing as an example, in Japan 51.7 percent of the men did not change jobs in a 10-year period, but in the United States only 30.3 percent had made no job change. (p.78).

Second, we may infer SHC investment from the overall growth of non-physical resources. Denison and Chung found that "advances in knowledge", a category which includes SHC, was about twice as high in Japan as in the United States in the

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[10] "General and specific training are convenient analytic terms, but they actually represent two poles of a continuum. Few types of training are completely specific to one company, and little on-the-job training could really be considered completely general." (Thurow, p.92).

[11] See Parsons (1972, p.1139) for some examples of this.

point that in the Japanese firm, there is

> an atmosphere in which people find it easy to cooperate productively horizontally and take care of unanticipated problems at the lowest effective level. (p.218).

Aoki (1990, p.5-6.) also describes enormous efficiency gains in terms of saved time and improved product quality through effective horizontal coordination in Japanese automobile and steel industries. An MIT commission on industrial productivity with Dertouzos, Lester, Solow and others as its members had a similar view.[14]

Productivity increases from workplace cooperation are not gained without a cost; there is no free lunch, as economists like to say. It certainly takes time for people to get to know each other, and more time for people to build up trust and confidence in each other.[15] A classical example used to describe SHC

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equally efficient, except that it had to hire a fairly large proportion of individuals to do the interstitial jobs, and to check on the interstitial quality of work between job boundaries. No such individuals were required in the Japanese enterprise. Those who carried out work within the job boundaries were not concerned about doing what was necessary to coordinate with others, nor about the possible spillover into other people's jobs." (Leibenstein, 1987, p.209).

[14] The committee made the following comments. "In Japanese firms the hierarchy has fewer levels and it is layered rather than strictly tree-like: people in one layer generally know and can easily communicate with people in the next-higher and next-lower layers, regardless of departmental boundaries." (p.97). In contrast, "American firms have several extra layers of hierarchy arranged as an organizational tree. To communicate with one another, people working in different departments often have to go up the tree to their lowest-level common superior and then back down." (p.97).

The commission also pointed out that "underdeveloped cooperative relationships between individuals and between organizations stand out in our industry studies as obstacles to technological innovation and the improvement of industrial performance." (p.94).

[15]. In "The Evolution of Cooperation", Robert Axelrod told some interesting stories of how, in World War I, trench warfare in the western front often turned into local truces. Local truces required cooperation between the two opposing sides. This involved a process in which the two sides came to understand each other's intentions, developed a moral standard to serve as a base on which acceptable rules of behavior were defined, and established enforcement mechanisms.

Many Americans complain about the slowness of the Japanese in doing business. The Japanese way of doing business is based on the principle, however, that unless people become familiar with each other on a personal level, business relations can only be limited. Those Americans who realize this and remain patient and persistent usually find the payoffs very

time and energy means to the personal life of a Japanese worker.

> Even an employee's family takes second place (in terms of time, mental energy, and emotional output) to his unit at work. ...[The company] guarantees security in one's lifetime, and in return it demands total dedication. (p.161).

Because they are costly to establish but once established can contribute to productivity gains, the spirit and skills involved in good workplace cooperation should be viewed as a form of SHC. There are good reasons to believe that such spirit and such skills are what the Japanese take pains to cultivate, and that they are a major source of the Japanese industrial strength. Given the experience of Japanese firms, it is regrettable that this important form of SHC has not received sufficient attention in studies of SHC.

VIII. Summary and Concluding Remarks

We have for the first time shown how three closely related variables - a worker's wage level, his SHC investment, and his probability of separation from an employer - are endogenously and simultaneously determined by the worker's productivity uncertainty. When productivity is very uncertain, a worker is likely to be paid a lower wage; he will respond to the lower wage by investing less in SHC; and the employment relationship will also be less stable. Hence a negative relationship is likely to exist between the level of productivity uncertainty and that of the worker's investment in SHC. For this reason, the average value of the worker to the firm is also lower when there is greater uncertainty about the worker's productivity, everything else equal.

Our study is inspired by a comparison of the Japanese worker's investment in SHC with that of his American counterpart. Heavier investment in SHC by the Japanese worker is evidenced by a more stable employment relationship, the worker's greater loyalty to the firm, and his excellent workplace cooperation

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leaders in business and industry undoubtedly possess great personal managerial ability: they are the ones who act in a more authoritarian way and lay down the grand design within which the total organization is to function." (Helvoort, p.117)

in practice by the magnitude of the increase in employment stability.[18] It can be argued that whatever the initial market conditions that generate a given level of uncertainty, these conditions can always be modified by appropriate public policies ranging from legal or regulatory to tax, financial, government procurement, and international economic policies. The triumph of the Japanese automobile industry is a very good example of effective use of all these policies.[19] The argument here is not just the familiar one on infant industries. It suggests that even for a technologically leading industry, if SHC is critical for its continued success but market conditions have become too volatile for further development or maintenance of this capital resource, then there is a role that the government can play in helping the industry to maintain its competitive edge. Although government intervention cause certain welfare losses, lack of appropriate public policies to protect the firm's human capital resources and encourage SHC growth can also have far-reaching, adverse effects on social welfare. The two sides must then be balanced in the making of public policy. The issue is thus one of how to do it right than one of whether or not the government should do anything.

Mathematical Appendix

Proposition 6: Define

$$s_o \equiv \frac{2^{1-2p}\Gamma(2p)}{\Gamma(p)\Gamma(p)} \int_{-1}^{-(2p-1)^{-1/2}} (1 - t^2)^{p-1} dt \ .$$

Given a beta distribution, then $(dw_o/d\sigma) > 0$ if and only if $s < s_o$ or $s > 1-s_o$; and $(dw_o/d\sigma) < 0$ if and only if $s_o < s < 1-s_o$.

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[18] Parsons (1972, p.1140) convincingly argues for the possible need for using public policy to reduce labor mobility as an optimal adjustment to growing stocks of firm-specific human capital. It is interesting to compare the similarity as well as the difference between his policy recommendation and ours.

[19]. See Odaka, Ono and Adachi, pages 40, 45-7 and 51 for a more detailed account on the role of government policies in promoting the Japanese automobile industry.

A more or less similar story was part of the reason for the American dominance in the commercial aircraft industry. See MIT Commission, page 11.

this paper.

Proposition 8: In equilibrium, if $Kc^{\alpha} > \underline{w}$, then the probability of separation increases as productivity uncertainty increases, i.e., $(ds/d\sigma)>0$. $Kc^{\alpha} > \underline{w}$ is also a necessary condition for $(ds/d\sigma)>0$ to be true.

Proof: The probability of separation is

$$s = \text{prob}(\theta<w_o) = \int_{-\infty}^{w_o} \sigma^{-1} f[(x - Kc^{\alpha})\sigma^{-1}]dx$$

Proposition 4 gives

$$Kc^{\alpha} = (1 - \alpha)(w_o - \underline{w})/\alpha \ .$$

Substituting, we have

$$s = \text{prob}(\theta<w_o) = \int_{-\infty}^{w_o} \sigma^{-1} f[x\sigma^{-1} - (1 - \alpha)(w_o - \underline{w})\alpha^{-1}\sigma^{-1}]dx$$

Changing the dummy variable from x to $t = (x/\sigma)$, we have

$$s = \text{prob}(\theta<w_o) = \int_{-\infty}^{w_o/\sigma} f[t - (1 - \alpha)(w_o - \underline{w})\alpha^{-1}\sigma^{-1}]dt$$

Differentiating with respect to σ, we have

$$ds/d\sigma = [(d/d\sigma)(w_o/\sigma)]f[(w_o/\sigma) - (1 - \alpha)(w_o - \underline{w})\alpha^{-1}\sigma^{-1}]$$

$$- (1 - \alpha)\alpha^{-1}[(d/d\sigma)[(w_o - \underline{w})/\sigma]] \int_{-\infty}^{w_o/\sigma} f'[t - (1 - \alpha)(w_o - w)\alpha^{-1}\sigma^{-1}]dt$$

$$= [(d/d\sigma)(w_o/\sigma)]f[(w_o/\sigma) - (1 - \alpha)(w_o - \underline{w})\alpha^{-1}\sigma^{-1}]$$

$$- (1 - \alpha)\alpha^{-1}[(d/d\sigma)[(w_o-\underline{w})/\sigma]]f[t - (1 - \alpha)(w_o - \underline{w})\alpha^{-1}\sigma^{-1}] \Big|_{t=-\infty}^{t=w_o/\sigma}$$

Notice that $y = [(2 - (1/\alpha))w_o + ((1/\alpha) - 1)\underline{w}]/\sigma$, as given in Proposition 5. Thus

$$ds/d\sigma = f(y)(dy/d\sigma),$$

and $ds/d\sigma$ and $dy/d\sigma$ have the same sign. From the proof of Lemma B, we know that in equilibrium y satisfies

D. $\quad \sigma(w_o - \underline{w})^{(1/\alpha)-2} = K_1 f(y).$

Substituting w_o in terms of y, we have

$$\sigma(\underline{w} - \sigma y)^{\mu} = K_4 f(y),$$

$< \sigma^{-1}[\,|Kc^{\alpha}\ (1-2\alpha)/(1-\alpha)|\ +\ \underline{w}]$

$< \delta$

where the last inequality is derived from $Kc^{\alpha} < (\underline{w} + \delta\sigma)(1-\alpha)/(1-2\alpha)$. By the definition of δ, $f(y)+yf'(y) > 0$, which implies that $dw_o/d\sigma < 0$. Combining this with Proposition 8, we prove the first part of the corollary. In the proof of Corollary B, we showed that Kc^{α} is an increasing function of K for any given σ. Therefore the second part of the corollary is implied by the first part of the corollary. ∎

Lemma B: $K_4f'(y) + \sigma^2\mu(\underline{w} - \sigma y)^{\mu-1}$ defined in the proof of Proposition 8 is positive.

Proof: $K_4f'(y) + \sigma^2\mu(\underline{w} - \sigma y)^{\mu-1}$

$= K_1\mu^{\mu}\ f'(y) + \sigma^2\ \mu(\underline{w} - \sigma y)^{\mu-1}$

$= \mu^{\mu}\ [K_1f'(y) + \sigma^2\ \mu^{1-\mu}(\underline{w} - \sigma y)^{\mu-1}\ ]$

$= \mu^{\mu}\ [K_1f'(y) + \sigma^2\ (w_o - \underline{w})^{(1/\alpha)-3}\ ]$ (by Prop. 5)

$= \mu^{\mu}\ K_1\ [f'(y) + \sigma(w_o - \underline{w})^{-1}\ f(y)\ ]$ (by D. in Corollary A)

$= \mu^{\mu}\ K_1\ [f'(y) + \sigma(1-\alpha)(K\alpha)^{-1}\ c^{-\alpha}\ f(y)\ ]$ (by Prop. 4)

$> 0.$ (by Lemma A) ∎

Proposition 7: $\{s_o(p)\}_{p=2}^{\infty}$ is an increasing sequence, and $s_o(p=\infty) < 0.159$.

Proof: We first prove that $\{s_o(p)\}_{p=2}^{\infty}$ is an increasing sequence.

When p is an integer, $\Gamma(p) = (p-1)!$. Therefore

$$s_o(p) = [2^{1-2p}(2p-1)!/(p-1)!(p-1)!] \int_{-1}^{-(2p-1)^{-1/2}} (1 - t^2)^{p-1}dt\ .$$

Let $P = -(2p-1)^{-1/2}$. Integrating by parts, we have

$\int_{-1}^{P} (1-t^2)^{p-1}dt$

$= t(1 - t^2)^{p-1}\Big|_{-1}^{P} - \int_{-1}^{P} 2(p-1)t^2(1 - t^2)^{p-2}dt$

$= P[(2p-2)/(2p-1)]^{p-1} + \int_{-1}^{P} (2p-2)(1-t^2)^{p-2}dt - \int_{-1}^{P} (2p-2)(1-t^2)^{p-1}dt$

Rearranging terms, we have

$$\int_{-1}^{P}(1-t^2)^{p-1}dt = [(2p-2)/(2p-1)]\int_{-1}^{P}(1-t^2)^{p-2}dt + P^3[(2p-2)/(2p-1)]^{p-1}.$$

Substituting the above equation into $s_o(p)$ and canceling terms yield

$$> \exp\{(1-3x)[-2x^2 + 6^{-1}g'''(x)x^3]/2x\}$$

$$= \exp\{(1-3x)[-x + 12^{-1}g'''(x)x^2]\}$$

$$\geq 1 + (1-3x)[-x + 12^{-1}g'''(x)x^2] \ .$$

The last inequality is true because $e^z \geq 1 + z$, for all z. If $p \geq 10$, then $x \leq 1/19$. Because $g^{(4)}(x) < 0$,

$$g'''(x)/12 \geq g'''(1/19)/12 > -5.5.$$

Therefore,

$$[(2p-4)(2p-1)/(2p-3)(2p-2)]^{p-2}$$

$$> 1 + (1-3x)(-x-5.5x^2)$$

$$= 1 - x - 2.5x^2 + 16.5x^3$$

$$> 1 - x - 2.5x^2 \ .$$

Let $h(x) = (1-2x)^{-1/2}$. Again using Taylor expansion, we can show that

$$h(x) > 1 + x + 3x^2/2 \ .$$

we now have

$$I(p)[(2p-1)^{p-.5}/(2p-2)^{p-2}]$$

$$> x^{-1}[h(x)-1][(2p-4)(2p-1)/(2p-2)(2p-3)]^{p-2} - 1$$

$$= x^{-1}[h(x)-1-x][(2p-4)(2p-1)/(2p-2)(2p-1)]^{p-2}$$

$$+ [(2p-4)(2p-1)/(2p-2)(2p-1)]^{p-2} - 1$$

$$> 1.5x(1-x-2.5x^2) - x - 2.5x^2$$

$$= 0.5x - x(4x+3.75x^2)$$

$$> 0.5x - x[(4/19) + (3.75/19^2)]$$

$$> x/4$$

$$> 0.$$

Therefore, we have shown that

$$s_o(p) > s_o(p-1), \text{ for } p \geq 10.$$

The monotonicity of the leading terms (p = 2, 3, ...9) is apparent from the table below. This proves that $\{s_o(p)\}_{p=2}^{\infty}$ is a monotonically increasing sequence.

Next we prove that s_o has an upper bound smaller than 0.159.

In the first half of this proof, we had

$$s_o(p) = s_o(p-1) + I(p)[2^{3-2p}(2p-3)!/(p-2)!(p-2)!] \ .$$

$$< (2p-3)[4\pi(p-2)]^{-1/2}\exp\{(24p-48)^{-1}\}\ \frac{3(2p-2)^{p-2}(2p-1)^{3/2}}{2(2p-1)^{p-.5}(2p-3)^{5/2}}$$

$$= (3/4)[\pi(p-2)]^{-1/2}\exp\{(24p-48)^{-1}\}[(2p-2)/(2p-1)]^{p-2}(2p-3)^{-3/2} .$$

Let $t = p^{-1}$. Then

$$s_o(p) - s_o(p-1)$$

$$< (3/8)(2\pi)^{-1/2}p^{-2}\exp\{(24p-48)^{-1}\}(1-2t)^{-1/2}(1-1.5t)^{-3/2}$$

$$[(1-t)/(1-.5t)]^{(1-2t)/t}.$$

$$(1-2t)^{-1/2}(1-1.5t)^{-3/2}[(1-t)/(1-.5t)]^{(1-2t)/t}$$

$$= \exp\{t^{-1}[\ln(1-t)-\ln(1-.5t)] - 2\ln(1-t) + 2\ln(1-.5t)$$

$$- .5\ln(1-2t) - 1.5\ln(1-1.5t)\}.$$

Let $\phi(t)=\ln(1 - t)-\ln(1 - .5t)$. Then $\phi(0)=0$, $\phi'(0)=-1/2$, $\phi''(0)=-3/4$, and $\phi'''(t) < 0$. Thus

$$\phi(t) = \phi(0) + \phi'(0)t + .5\phi''(\xi)t^2$$

$$< \phi(0) + \phi'(0)t + .5\phi''(0)t^2$$

$$= -.5t - .375t^2 ,$$

where $\xi\epsilon(0, t)$. Let

$$\psi(t) = -2\ln(1-t) + 2\ln(1-.5t) - .5\ln(1-2t) - 1.5\ln(1-1.5t).$$

Then $\psi(0) = 0$, and

$$\psi'(t) = [2/(1-t)] - [1/(1-.5t)] + [1/(1-2t)] +(9/4)[1/(1-1.5t)]$$

$$< [2/(1-t)] + [1/(1-2t)] +(9/4)[1/(1-1.5t)] - 1 .$$

If $p \geq 500$, then $t \leq 1/500$, and

$$\psi'(t) < 4.27 .$$

Thus $\psi(t) = \psi(0) + t\psi'(\xi) < 4.27t$. Therefore

$$(1-2t)^{-1/2}(1-1.5t)^{-3/2}[(1-t)/(1-.5t)]^{(1-2t)/t}$$

$$< \exp\{-.5 - .375t + 4.27t\}$$

$$< e^{-1/2}e^{3.9t} .$$

This implies that

$$s_o(p) - s_o(p-1)$$

$$< (3/8)(2\pi e)^{-1/2}p^{-2}\exp\{3.9t\}\exp\{(24p-48)^{-1}\}$$

$$< (3/8)(2\pi e)^{-1/2}p^{-2}(1.008)$$

Table: Values of s_o for p = 2, 3, ...45 and p = 500.

(These values of s_o are calculated on a NEXT station using the software *Mathematica*.)

p =	s_o =	p =	s_o =	p =	s_o =
2	.1151	16	.1547	31	.1567
3	.1332	17	.1550	32	.1567
4	.1408	18	.1552	33	.1568
5	.1448	19	.1554	34	.1568
6	.1474	20	.1555	35	.1569
7	.1491	21	.1557	36	.1569
8	.1505	22	.1558	37	.1570
9	.1514	23	.1560	38	.1570
10	.1522	24	.1561	39	.1571
11	.1528	25	.1562	40	.1571
12	.1533	26	.1563	41	.1572
13	.1537	27	.1564	42	.1572
14	.1541	28	.1564	43	.1572
15	.1544	29	.1565	44	.1573
		30	.1566	45	.1573
				500	.1585

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