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BEING KNOWLEDGEABLE OR SOCIABLE?: DIFFERENCES IN RELATIVE IMPORTANCE OF COGNITIVE AND NON-COGNITIVE SKILLS

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Being Knowledgeable or Sociable?: Differences in Relative Importance of Cognitive and Non-cognitive Skills

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Abstract

This paper develops a model of college admissions that emphasizes their role as a human capital evaluation method. Given multiple dimensions of human capital, different pattens of human capital evaluation and develpment emerge as equilibria. These equilibria with a varying emphasis on different aspects of human capital can match an observed difference in college admission patterns between East Asian countries and the U.S. The model has a macroeconomic implication about the relationship between measured human capital and economic performances. We demonstrate the support for this implication through cross-country regressions.

1 Introduction

University admissions provide an important evaluation method of human capital. College wage premium exists,[1] and part of it can be explained by a signalling theory - individuals with more developed human capital are more likely to attend higher education, or a higher education institution will admit only those individuals.[2] University admissions can also work as a major guideline for individuals concerning what kind of human capital they should equip themselves with in order to be productive in a society. This paper introduces a model of university admissions that emphasizes their role as a human capital evaluation method. Though college admissions have been a subject of research from various perspectives,[3] this paper, to our knowledge, is the first theoretical attempt to

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[1]For example, the hourly wages of college graduates are about 60% higher than those of high school graduates with 1 to 3 years of experience in 1990s of the U.S. (Fang 2006)

[2]The screening by higher education institutions, in an extreme case, is so perfect that the income prospect of individuals is not dependent on the specific institution they attended if admission results to various institutions are similar (Dale and Krueger 2002).

[3]It has been a subject of a matching problem since Gale and Sharpley (1962). Specific aspects of college admissions such as an affirmative action (Bowen and Bok 1998 among others) or an early admission (Avery et.al 2003 and Lee 2009) have also been hotly debated.

Table 1: Admissions Standards of Korean Universities

		Components of Admissions Evaluation			
		KSAT	High School Record		Essay Test
			Curricular	Extracurricular	
SNU	Preliminary (200% of class)	100			
	Final	20	40	10	30
Korea Univ.	Priority (70% of Class)	100			
	General (30% of Class)	50	45	5	

emphasize this role.[4] By modeling an interaction of universities' admissions standards and students' decisions of human capital investment, we show that different evaluation and development patterns of human capital emerge as equilibria. Such different patterns can match empirical patterns we observe between East Asian countries and the U.S. Moreover, these patterns have a macroeconomic implication about the relationship between measured human capital and economic performances. Using a cross-country data set, we estimate this relationship and find a reasonable support for the empirical relevance of the model.

The empirical pattern we want to highlight is a stark difference in observed university admissions standards between East Asian countries and the U.S. While academic institutions in East Asia predominantly use academic measures when admitting students, those in the U.S. use other measures such as leadership and community involvement in addition to academic measures. Table 1 shows the regular admissions standards of Seoul National University (SNU) and Korea University.[5] The important components are KSAT (Korean SAT), which is a nation-wide exam, and an essay test. These components are all academic. SNU places 30% weights in essay writing tests in the second round of selection, which measure mostly an academic ability. The only possible non-academic component is extra-curricular activities in high school records, which is given 5 to 10% weights.[6]

Institutions in the U.S. rarely announce their admissions standards publicly. According to guides in web sites of Harvard and Yale University, however, non-academic qualities such as leadership, community involvement, curiosity, etc. are important in addition to academic accomplishments.

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[4]Impacts of university admissions on high school education is well recognized by its practioners. See Atkinson (2001).

[5]They do not apply to the school of education and the school of arts, where an interview or a portfolio of the art works can play a role.

[6]Even this component can be mostly academic, since award winning records in various academic competitions such as math olympiad count highly in this component. Recently, employing financial incentives, the Korean government tries to encourage universities to introduce new admissions practices that are based on the evaluation of admission officers. In early admissions, we may have seemingly quite different admissions standards. But it is still controversial whether the new practice really changes how universities admit students.

Figure 1: Admissions Rates according to Ratings; US Instituion [Source: Avery et.al (2001)]
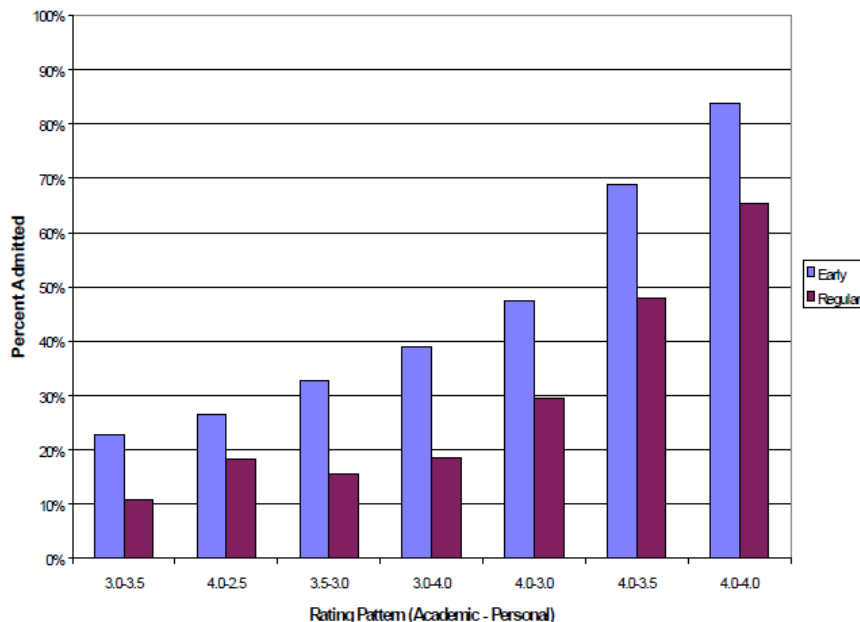

Figure 1, which is a direct quote from Avery et.al (2001), shows the admission rates of one institution according to the ratings of admission officers. This institution has a personal rating as well as an academic rating, and the admission rates vary according to the pair of these ratings. It is evident that the personal rating also affects the admissions rates.

These clear differences in human capital evaluation lead to different patterns of human capital development in both societies. If we compare time use of high school students, East Asian students spend most of their time on academic activities, while U.S. students divide their time between academic activities and non-academic activities such as sports. While Japanese high school students spend 60.4 hours per week on school work, U.S. students spend 30.0 hours on it. Instead U.S. students spend more time in 'playing games and sports' (7.0 hours per week) than Japanese students (0.7 hours per week).[7] Comparison results are similar between the U.S. and Korea. U.S. students spend 6.3 hours on educational activities on an average weekday, while Korean students spend 10.7 hours on them. Again U.S. students spend more time on socializing and sports (4.6 hours) than Korean students (2.0 hours).[8]

All these differences of human capital evaluation and development, however, cannot be wholly

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[7]This comparison is based on years 1981-82 for U.S. and 1986 for Japan (Juster and Stafford 1991).

[8]Such findings are from American Time Use Survey (http://www.bls.gov/tus/charts/students.htm) and Korean Time Use Survey (http://kosis.kr).

ascribed to discrepancies in desirable characters of human capital. Non-academic factors also seem to be very important in East Asian societies. According to a survey on employers in Korea,[9] important evaluation components in a job interview include non-academic factors such as responsibility (19.7%), a capability to cooperate (13.4%), and communication skills (12.7%) as well as academic factors - job related knowledge (20.8%). Many earnings regressions show that academic factors (or cognitive abilities) are very important in the U.S. As economic environment is globalized, however, we expect the contribution of human capital to the economy would become similar especially among relatively advanced economies.

This paper offers an explanation about persistent differences in human capital development patterns between countries. We develop a model with multiple dimensions of human capital where a university tries to recognize and admit the most productive students and students develop human capital to be successful in university admissions. Kinds of human capital to be analyzed are cognitive skills usually meaning academic achievement and non-cognitive skills such as leadership and social skills.

A coordination problem arises, since a certain type of human capital, to be utilized, should be both developed and then recognized as productive. Students would have an incentive to develop more a type of human capital that is more likely to be recognized. Universities would have an incentive to more correctly recognize a type of human capital if there are more students equipped with it. Therefore, we can have multiple coordinations: one involves low investment and less recognition while the other involves high investment and more recognition. Moreover, since students have limited time to invest in human capital, there will be a trade-off between the two dimensions (cognitive and non-cognitive) of human capital. If students invest more in one aspect of human capital, they have to reduce their investment in the other aspect.

With the coordination problem and trade-off combined, there can be multiple equilibria with different emphases on each type of human capital. If a university recognizes cognitive skills more, students will invest more in cognitive skills and have to reduce their time on non-cognitive skills. This will in turn induce the university to recognize less of non-cognitive skills and more of cognitive skills. If universities recognize non-cognitive skills more, the same logic will lead to an enhancement of non-cognitive skills. Especially, we can have coexisting equilibria with a complete emphasis on cognitive skills alone and with a similar emphasis on both skills.

Multiple aspects of human capital we assume in the model are recently getting growing attention in economic analysis. Traditionally, human capital has been equated with cognitive skills measured by IQ or other test scores in economic analysis. This is because the measures of cognitive skills are more readily available than those of non-cognitive skills, not because it is the only important aspect of human capital (Carneiro and Heckman 2003). There have been new empirical analyses

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[9] A news release by the Korea Employers Federation, 2006.

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which also consider effects of non-cognitive skills on labor market and schooling outcomes (Borghans et.al 2008, Cunha and Heckman 2008, Heckman et.al 2006 among others). These studies generally confirm non-negligible effects of non-cognitive skills. Non-academic measures used in the admission process of U.S. institutions such as leadership quality, community involvement, or personal ratings seem to accommodate the importance of non-cognitive skills.

It is also believed that non-cognitive skills can be obtained as a by-product of participation in social activities such as sports, drama club, student government, and so on (Postlewaite and Silverman 2005). The wage premium generated by participating in sports activities may be due to the development of non-cognitive skills (Stevenson 2010). Time used in these activities, therefore, can be thought of as an investment in non-cognitive skills.

Taking multiple dimensions of human capital into account, multiple equilibria of our model can match with the empirical patterns described above. In East Asian countries, we see more investment on cognitive skills (more time spent on academic activities) and more recognition of them in university admissions. On the contrary, in the U.S., we have relatively more investment in non-cognitive skills (more time spent on sports and socialization) and more recognition of them in university admissions.

Our results also shed light on an international comparison of test scores and its implications. High scores in international tests are usually interpreted as a better educational quality and are reported to be related with better economic performances (Jamison et.al 2006 and Hanushek and Woessmann 2008 among others). These test scores are, however, measures of cognitive skills only, and measures of non-cognitive skills should be accounted for to correctly evaluate the relationship.[10] Moreover, due to the aforementioned trade-off between two skills, the presence of an omitted variable may systematically bias an estimate of the impact of cognitive skills on economic outcomes. We suggest that the time use pattern of test takers can be used to alleviate such an omitted variable problem.

In the final part of the paper, we implement an empirical exercise following the above idea. Our empirical analysis reasonably supports the implications of the model. The time share invested in non-cognitive skills is positively related to economic performances and adding the time use variable tends to increase the effect of test scores on economic outcomes as predicted.

This paper proceeds as follows. Section 1.1 briefly discusses the related literature. Then we introduce the model in Section 2 and analyze it in Section 3. Section 4 contains a brief discussion on model settings. Section 5 discusses and tests empirical implications of the model. Then the conclusion follows.

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[10]Even though this is recognized in Hanushek and Woessmann (2008), non-availiability of the measures of non-cognitive skills seems to let them go on with the analysis.

1.1 Related Literature

Multiple aspects of human capital is recently gaining more attention in economics (Carneiro and Heckman 2003, Heckman et.al 2006, Cunha and Heckman 2007 and 2008, Borghans et.al 2008 among others). Studies empirically show a positive return of non-cognitive skills. This paper, to our knowledge, is the first theoretical undertaking that deals with different patterns of human capital evaluation with multiple dimensions of human capital.

This paper is directly related to Lee (2007) in that differences in studying time of high school students between the U.S. and East Asian countries are explicitly analyzed. Lee indicated that U.S. students study more in college than in high school while the opposite is true for East Asian students, explaining that signalling of students' abilities happens in high school for East Asian countries while it occurs in college in the U.S. Our study explains discrepancies of universities' admissions standards which were not addressed in Lee.

Though the purposes of modelling and specific settings are very different, the idea behind the modeling framework of this paper is very similar to that of Mailath et al. (2000). Both Mailath et.al and this paper put together two coordination failure models whose idea is quite common (Diamond 1982, Coate and Loury 1993 among others). Mailath et al. assume two groups of workers and explain possible discrimination in the labor market by the interaction of search intensity of firms and skill investment decisions of workers. In this paper, we assume two kinds of skills and suggest a possibility of different treatments of the two skills. While they are more interested in one type of equilibrium (discriminating one), we are more interested in the coexistence of two types of equilibria (similar and unequal treatments of two skills).

Another branch of the literature this paper is related to is studies that emphasize the importance of cognitive skills in a country's economic development. In a series of papers, Hanushek and colleagues (Hanushek and Kimko, 2000; Jamison et al., 2006; Hanushek and Woessmann, 2008) show that besides the quantity, the quality of human capital as measured by cognitive test scores of international standardized tests matters in a country's economic performance. Drawing an attention to the importance of non-cognitive human capital, this paper adds another dimension of human capital as a determinant of economic development. Not only does this paper supplement the recent growth literature but it also offers a cautionary note to interpretations of the results drawn from conventional empirical specifications of growth regressions. If one acknowledges the role of non-cognitive human capital in economic development, she is bound to admit that there is a trade-off between cognitive and non-cognitive skill investments. Such a trade-off opens a possibility that the existing empirical specifications of the growth literature that control for a measure of cognitive human capital alone may yield a bias due to the failure to consider the role of non-cognitive human capital. Fortunately, however, such a bias reinforces rather than attenuates the importance of

cognitive human capital in economic development.

2 Model

Human Capital   We assume there are two kinds of human capital, HK_i for $i = 1, 2$. We consider cognitive skills, which are usually measured by academic achievement, as HK_1 and non-cognitive skills such as leadership, communication skills, and social skills as HK_2.[11]

Student-Workers   There are a unit mass of identical student-workers. They can invest in HK_1 and HK_2. Let t_i be the time invested in each type of human capital.

They can be either equipped with human capital or not. The probability of being equipped with human capital depends on the time investment. For simplicity, we assume that the probability of being equipped with each type of human capital is equal with a same time investment. Specifically $f(t)$ is the probability of being equipped with human capital if time t is invested. Then $f(t_1)$ and $f(t_2)$ are the probabilities of being equipped with each type of human capital. As a probability, f lies between 0 and 1 with $f(0) = 0$ and $\lim_{t \to \infty} f(t) = 1$. We assume f is increasing and concave: $0 < f' < \infty$, $f'' < 0$.

The utility cost of the time investment is $c(t_1 + t_2)$. We assume that this cost function is increasing and convex: $c' \geq 0$ with $c'(0) = 0$ and $c'' > 0$.

University-Firm   A university-firm has two kinds of positions, $j = 1, 2$ and can admit or hire student-workers for each position. Let v be the value a student-worker produces when (s)he is hired. If a student-worker, who is equipped with HK_1, is admitted or hired for position 1, then $v = \phi_1$. If a student-worker, who is equipped with HK_2, is admitted for position 2, then $v = \phi_2$. Let us call ϕ_i the productivity of HK_i. If a non-qualified student-worker is admitted for each position, then $v = -D$, i.e., a net loss incurs. If a student-worker is not admitted, (s)he will produce nothing. A student-worker equipped with both HK_1 and HK_2 can be admitted for both positions at the same time. Then her or his production is $\phi_1 + \phi_2$.

A university-firm cannot directly observe whether a student-worker is equipped with the human capital, but it can invest in a technology to recognize the human capital. Let p_i be the probability of recognizing HK_i if one has it. The cost of acquiring the technology p_i is $\psi(p_i)$ with

$$\psi(0) = 0, \; \lim_{p \to 1} \psi(p) = \infty, \; \psi' \geq 0 \text{ with } \psi'(0) = 0,^{12} \; \psi'' > 0.$$

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[11]Even though there can be many subdivisions in these skills (Borghans et.al 2006), we just follow this widely used classification for analytical convenience.

[12]The condition $c'(0) = \psi'(0) = 0$ is not essential. It is just for expositional convenience.

The cost of investment in two recognition technologies is separable, so that the cost of acquiring technologies p_1 and p_2 is $\psi(p_1) + \psi(p_2)$. We also assume that there is no more additional cost once the recognition technology is obtained. That is, the recognition technology can be applied to student-workers without any cost.

Utility or Profit   The wage of a student-worker is determined through a bargaining process. We will assume that the bargaining process results in an equal sharing of a produced value given that it is positive. That is, the student-worker's wage w is $\frac{1}{2}\phi_i$ if (s)he is hired in position $j = i$ and the university-firm's revenue R is $v - w$. For example, if a student-worker with HK_1 is hired for position 1, then $w = R = \frac{1}{2}\phi_1$. If a non-qualified student-worker is hired, then $w = \frac{1}{2}\phi_i$ and $R = -D - \frac{1}{2}\phi_i$. Of course, if a student-worker is not hired, $w = R = 0$.

A student-worker's utility u is the wage (s)he will get minus the cost of human capital investment:

$$u = w - c(t_1 + t_2).$$

The university-firm's profit π is the revenue it generates from admission or hiring minus the cost of investment on the recognition of each human capital. We abuse the notation, and denote R also as an integrated sum of revenue from all hired student-workers;

$$\pi = R - \psi(p_1) - \psi(p_2).$$

Time Line   The model follows the time line below:

1. The university-firm and the student-workers simultaneously make investment decisions. While the university-firm decides how much to invest in recognition technologies of each human capital p_i, the student-workers decide how much time to spend on the acquisition of each human capital t_i.

2. The student-workers' stochastic acquisition of human capital is realized.

3. The university-firm applies its recognition technologies to all the student-workers.

4. The university-firm makes an admission or hiring decision on each student-worker.

3   Analysis

We will analyze the model from the back. That is, we first analyze the university-firm's admission-hiring decision. Then we examine the investment decisions of the university-firm and the student-workers.

3.1 University-Firm's decision

3.1.1 Admission-Hiring Decision

In the first stage, the student-workers made investment decisions on t_i and the university firm on p_i. Since they are all identical, we restrict our attention to a symmetric equilibrium so that all student-workers made a same decision on t_i. Let us define $\gamma_i = f(t_i)$.

Note that a decision of admitting or hiring a student-worker in one position is totally independent of a decision in the other position. We take the university-firm's decision on each position separately.

Once the recognition technology is applied, a student-worker is either recognized as being equipped with human capital HK_i or not. If a student-worker is recognized as equipped with the human capital, the university-firm will admit or hire her (or him) in the relevant position since $R = \frac{1}{2}\phi_i > 0$.

If a student-worker is not recognized as equipped with the human capital, it is either because (s)he is not equipped with it or because it is not recognized although (s)he is equipped with it. The expected revenue of admitting or hiring one who is not recognized as being equipped with the human capital is

$$-\frac{(1-\gamma_i)}{(1-\gamma_i)+\gamma_i(1-p_i)}\left(D+\frac{1}{2}\phi_i\right)+\frac{\gamma_i(1-p_i)}{(1-\gamma_i)+\gamma_i(1-p_i)}\frac{1}{2}\phi_i. \tag{1}$$

We assume that D is large enough so that (1) is negative.[13] Then the university-firm will only admit or hire student-workers who are recognized as being equipped with the human capital.

3.1.2 Investment Decisions on Recognition technology

In the first stage, the university-firm should make investment decisions on recognition technologies for both kinds of human capital. Since the cost of investment is separable, the investment decisions related to each human capital are separately made.

Consider the investment decision on recognition technology for HK_i. Given student-workers' decisions γ_i, which is a portion of student-workers being equipped with HK_i, the university-firm's profit from HK_i, π_i, is

$$\pi_i = \frac{1}{2}\phi_i\gamma_i p_i - \psi(p_i).$$

A portion of student-workers who are equipped with the human capital and recognized as such by the university-firm is $\gamma_i p_i$. They generate the revenue $\frac{1}{2}\phi_i$. The optimal p_i^* that maximizes π_i satisfies the following FOC:

$$\frac{1}{2}\phi_i\gamma_i = \frac{1}{2}\phi_i f(t_i) = \psi'(p_i^*) \text{ for } i = 1, 2. \tag{2}$$

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[13]For the specific condition, see footnote 14.

Note that p_i^* is increasing in γ_i, henceforth in t_i. That is, as there are more student-workers equipped with HK_i to be recognized, it is more profitable to increase the possibility of recognizing them.

3.2 Student-Workers' Investment Decision on Human Capital

We turn to the student-workers' investment decision on HK_i. Given the university-firm's investment decision p_i, a student-worker's utility is

$$u = \frac{1}{2}\phi_1 p_1 f(t_1) + \frac{1}{2}\phi_2 p_2 f(t_2) - c(t_1 + t_2).$$

The following FOC will characterize the optimal t_i^*:

$$\frac{1}{2}\phi_i p_i f'(t_i^*) \leq c'(t_1^* + t_2^*) \text{ and equality holds if } t_i^* > 0 \text{ for } i = 1, 2. \tag{3}$$

Student-workers will invest until the marginal benefit of investment is equal to the marginal cost. If the marginal cost is larger than the marginal benefit, no investment will incur. If the optimal investment is interior, the student-workers will allocate their time investment so that the marginal benefit from each human capital investment is the same with each other and the same as the marginal cost:

$$\frac{1}{2}\phi_1 p_1 f'(t_1^*) = \frac{1}{2}\phi_2 p_2 f'(t_2^*) = c'(t_1^* + t_2^*).$$

Figure 2 graphically shows a student-worker's optimal time allocation. Given the university-firm's recognition technology p_i's, a student-worker will first invest in human capital with a greater marginal benefit, in this case HK_1. Once the marginal benefit of the investment for each human capital is the same, the additional time investment would be divided for both kinds of human capital until those marginal benefits are equal to the marginal cost of investment. At the optimum, therefore, the marginal benefits of the investment for both kinds of human capital are the same and they are equal to the marginal cost of investment.[14]
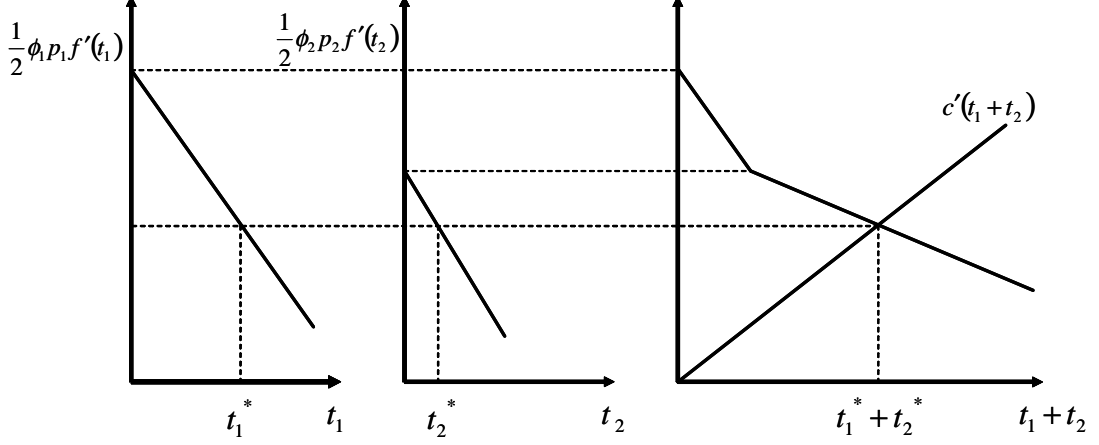
Suppose that p_1, the university-firm's investment in recognition technology for HK_1, increases. This will increase the marginal benefit for the student-workers' investment in HK_1, and hence t_1 will increase. Also, this increase in t_1 will increase the marginal cost and crowd out the investment for HK_2.

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[14]The maximum incentive to invest in HK_i is obtained when $p_i = 1$ and $t_j = 0$. In that case, the maximum investment $\overline{t_i}$ is obtained by

$$\frac{1}{2}\phi_i f'(\overline{t_i}) = c'(\overline{t_i}).$$

If we let $\overline{\gamma_i} = f(\overline{t_i})$, in any equilibrium $\gamma_i < \overline{\gamma_i}$. The expression (1) is largest when γ_i is large and p_i is small. Therefore, if $D \geq \frac{\overline{\gamma_i}}{1-\overline{\gamma_i}}\frac{1}{2}\phi_i - \frac{1}{2}\phi_i = \frac{2\overline{\gamma_i}-1}{1-\overline{\gamma_i}}\frac{1}{2}\phi_i$, (1) is negative for any possible γ_i and p_i.

Figure 2: Optimal Time Allocation for HK_1 and HK_2

We should note that there exists a complementarity between student-worker's investment and the university-firm's. The more university-firm invests in p_i, the more incentive student-workers will have to invest in HK_i, and vice versa. This raises a possibility that there can be multiple equilibria including both low investment coordination and high investment coordination. Moreover, it is also possible that they coordinate in equilibria emphasizing either HK_1 or HK_2 even with the same environment, which we will investigate in the next section.

3.3 Equilibrium

The equilibrium of the model is a combination of the university-firm's decision and student-workers' decisions which are consistent with each other. Therefore, the following equilibrium characterization results.

Proposition 1 *An equilibrium is a pair $\left((p_i^*)_{i=1}^2 , (t_i^*)_{i=1}^2 \right)$ which satisfies (2) and (3).*

To get a better grasp of the equilibrium characterization, we will focus on an equilibrium description involving t_1 and t_2 only. From (2), we define a function θ which gives the optimal p_i^* given t_i.
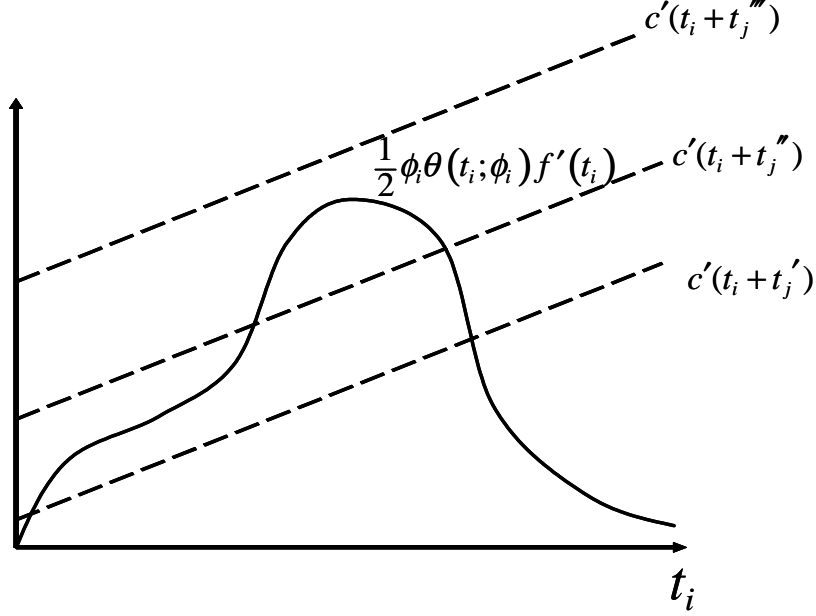
$$p_i^* = \left(\psi' \right)^{-1} \left(\frac{1}{2} \phi_i f\left(t_i \right) \right) \equiv \theta \left(t_i; \phi_i \right) \tag{4}$$

Function θ is an increasing function of t_i and ϕ_i since ψ' is increasing, and it is 0 when $t_i = 0$. If we plug (4) in (3), we get

$$\frac{1}{2} \phi_i \theta \left(t_i^*; \phi_i \right) f' \left(t_i^* \right) \leq c' \left(t_1^* + t_2^* \right) \text{ and equality holds if } t_i^* > 0 \text{ for } i = 1, 2. \tag{5}$$

Then, an equilibrium is $(t_i^*)_{i=1}^2$ satisfying (5).

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Figure 3: Equilibrium t_i when t_j is given

Corollary 1 *The equilibrium is $(t_i^*)_{i=1}^2$ satisfying (5).*

Figure 3 shows the determination of t_i with given t_j according to (5). Expression $\frac{1}{2}\phi_i\theta(t_i;\phi_i)f'(t_i)$ is 0 when $t_i = 0$ since $\theta(0) = 0$ and $f'(0)$ is finite, and approaches 0 as $t_i \to \infty$ since $\lim_{t_i \to \infty} f'(t_i) = 0$ and $\theta(t_i)$ is finite. It can have any shape in the middle; it will increase when the effect of increasing θ is dominant and decreases when the effect of decreasing f' is dominant. Expression $c'(t_i + t_j)$ is increasing in t_i given t_j. An intersection of the two graphs will give t_i satisfying (5) when t_j is fixed.

We can point out the following four things about the determination of t_i.[15] First, $t_i = 0$ always satisfies the condition whatever t_j is. The graph of c' is always (weakly) above the graph of $\frac{1}{2}\phi_i\theta(t_i;\phi_i)f'(t_i)$ when $t_i = 0$ (they are the same when $t_j = 0$ as $c'(0) = 0$). This will satisfy the inequality of (5). If student-workers do not invest in HK_i, the university-firm has no incentive to invest in the recognition technology for that human capital. If the university-firm does not recognize the human capital, student-workers would not invest in that human capital. Therefore, zero investment in HK_i always satisfies (5).

Second, we can have multiple intersections. As explained before, there exists a complementarity between the university-firm's investment and student-workers' investment. It is possible that they can coordinate in a lower investment level as they expect a low investment from each other. It

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[15]Intersections in Fig 3 are not euilibrium yet, since it only satisfies one equation in (5).

is also possible that they expect a higher investment from each other and coordinate in a higher investment level.

Third, when there are multiple intersections, they are Pareto ranked. If student-workers invest more in HK_i, the university-firm will be better off even with the same investment in the recognition technology. Since the university-firm optimizes its investment level at these intersections, the university-firm would be better off with a higher coordination. Likewise, student-workers would be better off in a higher investment coordination.

Fourth, there exists at least one stable intersection in the following sense.

Definition 2 *An intersection t_i is (locally) stable if there exists $\delta > 0$ such that for all positive t^0 satisfying $|t^0 - t_i| < \delta$*

$$\left(t^0 - t_i\right) \left[\frac{1}{2}\phi_i\theta\left(t^0; \phi_i\right) f'\left(t^0\right) - c'\left(t^0 + t_j\right)\right] < 0.$$

We can say t_i is (locally) stable if an investment level tends to increase (decrease) when it is slightly lower (higher) than t_i. Student-workers will increase an investment at t^0 if the marginal benefit is greater than the marginal cost, and decrease an investment otherwise. The above definition states that t_i is stable if the marginal benefit is greater (smaller) than the marginal cost when the investment level is lower (higher) than t_i. According to it, the intersections are stable if the graph of $\frac{1}{2}\phi_i\theta\left(t_i; \phi_i\right) f'\left(t_i\right)$ cuts that of $c'\left(t_i + t_j\right)$ from the above as t_i increases. When student-workers invest slightly more on HK_i, this will increase an investment in the university-firm's side. This in turn will provide more investment incentive for student-workers. On the other hand, f' decreases and c' increases, which will reduce an incentive of investment. If the former dominates the latter, then student-workers will increase an investment more and the intersection is not stable. Note that $t_i = 0$ is stable once $t_j > 0$ and may or may not be stable when $t_j = 0$ depending on whether the graph of $\frac{1}{2}\phi_i\theta\left(t_i; \phi_i\right) f'\left(t_i\right)$ is above that of $c'\left(t_i + t_j\right)$ near $t_i = 0$. If $t_i = 0$ is not stable when $t_j = 0$ (i.e., the graph of $\frac{1}{2}\phi_i\theta\left(t_i; \phi_i\right) f'\left(t_i\right)$ is above that of $c'\left(t_i + t_j\right)$ near $t_i = 0$), then the graph of $\frac{1}{2}\phi_i\theta\left(t_i; \phi_i\right) f'\left(t_i\right)$ should cut through that of $c'\left(t_i + t_j\right)$ from the above at some point since the former eventually goes to 0. Therefore, a stable intersection exists. Henceforth, we restrict our attention to the stable intersections.

Now we can define a relationship between investment levels in two kinds of human capital from Figure 3. That is, when t_j is given, we can find a stable intersection defining t_i. Let φ_i define the relationship. By abusing the notation, we write

$$t_i \in \varphi_i\left(t_j\right) \text{ for } i = 1, 2 \tag{6}$$

where t_i is a stable intersection in Figure 3 given t_j. The pairs (t_1, t_2) satisfying (6) will comprise a stable subset of equilibria. Note that φ_i is a correspondence as there can be many stable intersections for a given t_j.

Figure 4: Stuent-workers' equilibrium time allocation
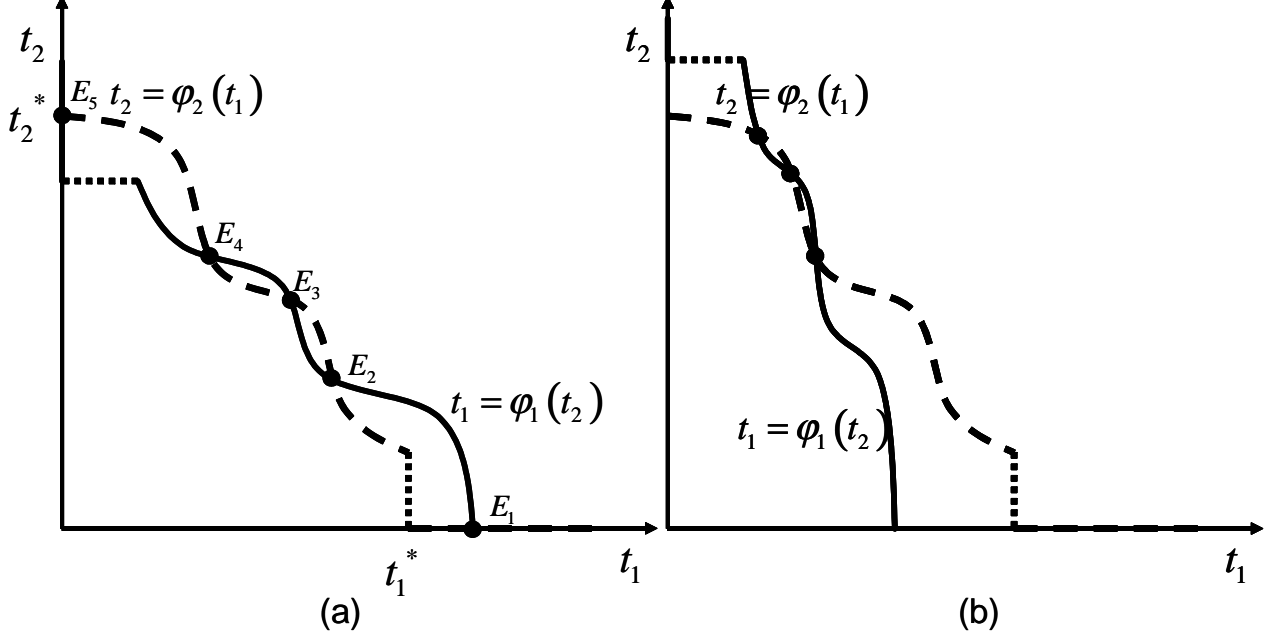
In the figure, we can see that for any stable intersections, the investment in HK_i decreases as the investment in HK_j increases. If t_j increases from t'_j to t''_j, the graph of c' moves up and the intersection t_i would decrease in any stable intersections. If the investment in the other kind of human capital increases, this will increase the marginal cost of time investment. Therefore, the investment for HK_i will decrease. Since this will trigger a decrease in the university-firm's investment, t_i will decrease further. If t_j increases further to t'''_j, then no investment will be made in HK_i.

Figure 4 shows φ_1, φ_2, and their intersections, which are stable equilibria in the sense of Definition 2. For expositional convenience, we ignore $t_i = 0$ when there are other stable intersections. We consider a case in which there is at most one stable intersection other than 0 as is the case in Figure 3. Then φ_i can be treated as a function. The intuition we get from the figure can be extended to a general case.

The graph φ_i is decreasing as explained and it is not continuous. Consider φ_1 for example (solid graph in the figure). It starts from a positive level at $t_2 = 0$ and decreases as t_2 increases. Once t_2 goes over a certain level, then φ_1 jumps to 0.

An equilibrium exists as there exists an intersection of two curves even though two curves are not continuous. As in panel (a), if φ_1 starts from over t_1^* when $t_2 = 0$, there exists an intersection with $t_2 = 0$. If φ_1 starts from under t_1^* and lies below φ_2, then φ_1 would end up below t_2^* and there

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should be an intersection with $t_1 = 0$. If φ_1 starts from under t_1^* and end up over t_2^*, then φ_1 should cross φ_2 as in panel (b). Therefore, an equilibrium exists. For later use, note also that φ_1 cuts φ_2 from below at least once as t_2 increases in all cases.

We can discuss another aspect of stability of an equilibrium. Even though an equilibrium is already stable one by the standard of Definition 2, we can add another definition of stability to an equilibrium in Figure 4.

Definition 3 *Suppose there exists an equilibrium E. We denote $t_1^{n+1} \equiv \varphi_1(t_2^n)$ and $t_2^{n+1} \equiv \varphi_2(t_1^n)$ in the neighborhood of E. An equilibrium E is (locally) stable if there exists $\delta > 0$ such that $\lim_{n \to \infty} (t_1^n, t_2^n) = E$ for all $(t_1^0, t_2^0) \in \mathbb{R}_+^2$ such that $\left\| (t_1^0, t_2^0) - E \right\| < \delta$.*

Definition 3 is a usual definition of stability that a system returns to the original equilibrium after small disturbances. According to this, an equilibrium is stable if φ_1 cuts φ_2 from below as t_2 increases. Suppose the university-firm increases the recognition of HK_1. Then student-workers increase an investment in HK_1 and reduce their time for HK_2. This will lead to a lower recognition of HK_2 and student-workers further reduce an investment in HK_2 and increase that in HK_1. The increase in the investment for HK_1 may or may not be large enough to justify the supposed increase in recognition of HK_1. If it is large enough, then this will further increase the recognition of HK_1 and the equilibrium is not stable. If it is not, then the increased recognition of HK_1 will roll back to the original level and the equilibrium is stable.

A stable equilibrium by Definition 3 exists as we already argued above that φ_1 cuts φ_2 from below at least once as t_2 increases. We will restrict our attention to stable equilibria in the following discussion and comparative statics.

Proposition 2 *A stable equilibrium satisfying (6) and Definition 3 exists.*

As illustrated in panel (a) of Figure 4, there can be many equilibria. According to Definition 3, E_1, E_3, and E_5 are stable while E_2 and E_4 are not. Even if we restrict our attention to stable equilibria only, we still have multiple equilibria in the figure. In these equilibria, we can say there exists a trade-off between two kinds of human capital. The marginal cost of time investment is dependent on the time spent on the other type of human capital. Moreover, there exists a complementarity between student-workers' investment and the university-firm's investment. Therefore, a higher investment and recognition coordination in HK_1 will lead to a lower investment and recognition coordination in HK_2. That is, if there is more emphasis on evaluation and development of one kind of human capital, the other kind of human capital is relatively ignored. In extreme equilibria like E_1 and E_5, we may have no investment at all in one kind of human capital.

Proposition 3 *Given economic environment $(\phi_1, \phi_2, \psi, f, c)$, we can have multiple stable equilibria. In these equilibria, we have a trade-off in evaluation and development between HK_1 and HK_2. If*

one equilibrium has more recognition and development of HK_1 than the other, it will have less recognition and development of HK_2.

In particular, equilibria like E_1 and E_3 can coexist under the same economic environment. In E_1, all the emphasis goes to cognitive skills as in East Asian countries. In E_3, cognitive and non-cognitive skills receive a similar emphasis as in the U.S. In East Asian countries, universities do not pay much attention to the recognition of non-cognitive skills ($p_2 = 0$) as students do not invest much in the development of these skills ($t_2 = 0$). Since universities do not recognize these skills, students do not have an incentive to invest in these skills. As a result, we observe admission standards centered on cognitive skills and students spending more time on academic activities. On the contrary, in the U.S., universities pay attention to non-cognitive skills as well as cognitive skills (positive p_1 and p_2). Students spend some of their time developing non-cognitive skills (positive t_1 and t_2). As students invest some time in non-cognitive skills, universities also pay attention to recognizing them.

3.4   Comparative Statics

In this section, we discuss an effect of a change in the economic environment on equilibria. We especially focus on two parameters. We first discuss an effect of a change in the productivity of human capital ϕ_i. In the main analysis, we assumed that the costs of the recognition technologies are the same. We relax this assumption and discuss an effect of cost differences.

3.4.1   Change in ϕ_i

Suppose that there is an increase in ϕ_2, i.e., non-cognitive skills become more important in the economy. In equation (5), this will directly increase the LHS since it will increase the payoff when admitted (or employed). Also it will indirectly increase the LHS since the university-firm will have more incentive to invest in the recognition technology, or $\theta(t_2; \phi_2)$ increases. The resulting change in φ_2 can be recognized in Figure 5.

As is clear in the figure, when the term $\frac{1}{2}\phi_2\theta(t_2; \phi_2) f'(t_2)$ increases, t_2 of any stable intersection will increase. Therefore, φ_2 will increase given t_1 as in Figure 6. As the graph of φ_2 moves upward, all the stable equilibria show an (weak) increase in t_2 and a (weak) decrease in t_1. Note that we can still have an extreme equilibrium E_1 as panel (a) shows. That is, even if the productivity of HK_2 is larger than that of HK_1 and the difference increases, it is possible that an economy remains in the equilibrium in which only HK_1 matters. If the productivity of HK_2 increases further enough, then the extreme equilibrium E_1 will disappear and we may observe some emphasis on HK_2 as E_1'' in panel (b). Of course, if we increase ϕ_2 further enough, then the unique equilibrium will be like E_3, that is, only HK_2 matters in the economy.

Figure 5: The effect of increase in ϕ_i on the shape of φ_i
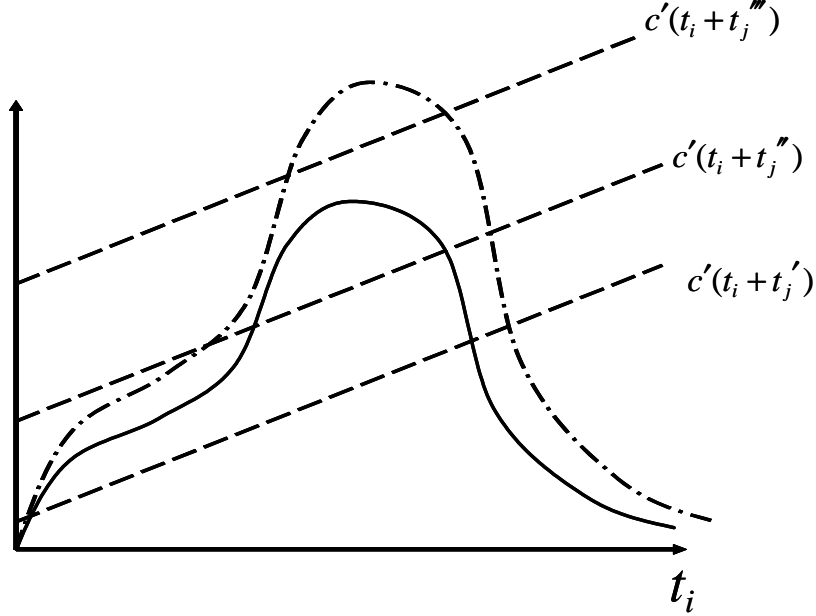
This analysis sheds some light on a change in East Asian countries in the future. Even if non-cognitive skills become more important, it may not be easy to move away from the present arrangement. Suppose some of universities start changing their admission practices. This may not affect students' behavior since a portion of changed universities might be small. Even if it does change students' behavior, it will take time and these universities should endure disadvantages in the meantime.

3.4.2 Change in an Investment Cost in Recognition Technology

We turn to an effect of a change in the recognition cost. In the main analysis, we assumed that the costs of investment in the recognition technologies are the same. However, one type of human capital may be harder to recognize than the other. For example, while HK_1 is relatively easier to recognize through various kinds of tests, HK_2 is hardly measured directly and is usually evaluated through circumstantial evidence such as a participation in activities which are deemed to increase HK_2. Here we assume that recognition technologies require different costs of investment, ψ_1 and ψ_2.

Suppose that HK_2 becomes easier to recognize. That is, ψ_2 decreases for any p_2. This will increase the LHS of equation (5). Therefore it will have qualitatively the same effect as an increase in ϕ_2 analyzed before. For any stable equilibria, t_1 (weakly) increases and t_2 (weakly) decreases.

Differences in the recognition technology in two kinds of human capital might be the main

Figure 6: The effect of increase in ϕ_2 on equilibria
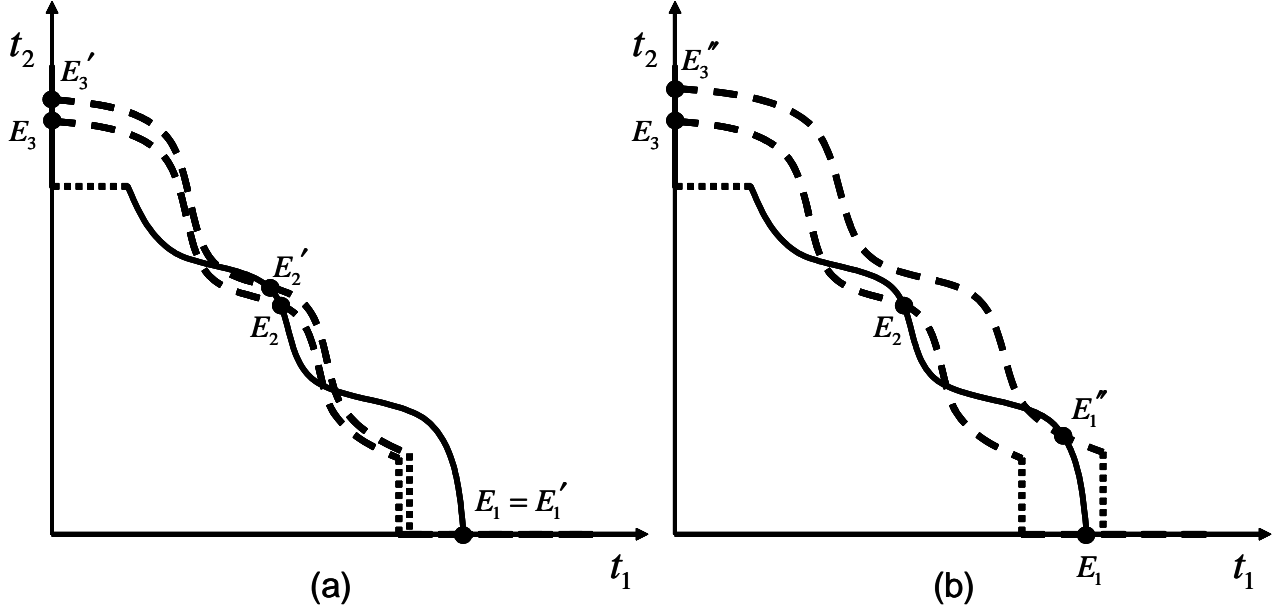
reason why we have the present arrangement in East Asian countries. It might have been much easier to observe and verify the accumulation of cognitive skills. Then paying attention to cognitive skills only might have been a unique equilibrium. It is possible, however, that they remain in that equilibrium even though recognition of non-cognitive skills becomes cheaper.

3.5 Welfare Analysis - An Illustration

When we have multiple equilibria which possibly represent different social arrangements in East Asia and the U.S., we are naturally interested in the Pareto ranking of these equilibria. The question is which arrangement will utilize human resources better with a given productivity of each skill.

If we jump to the answer, there is no generally-held Pareto ranking among equilibria. This will be illustrated in this section. We will compare the equilibrium with exclusive emphasis on HK_1 with the one with similar emphasis on both skills. If emphasis is exclusively put on one skill, the complementarity between the student-workers' investment and the university-firm's recognition will be fully exploited. However, this exploitation of complementarity comes with decreasing returns to investment. If the benefit of exploiting complementarity is larger than the cost of decreasing returns, the equilibrium with exclusive emphasis on one skill will yield a better outcome. Otherwise, the equilibrium with similar emphasis on both skills will be better.

Let us consider the social planner's problem. We maintain the constraint that both student-workers investment and the university-firm's recognition are necessary for HK_i to contribute to the

outcome of the economy. Then the economy's welfare W can be written as

$$W = \sum_{i=1}^{2} [\phi_i f(t_i) p_i - \psi(p_i)] - c(t_1 + t_2). \tag{7}$$

The social planner will choose $(t_i, p_i)_{i=1}^{2}$ to maximize W.

This is not a well-defined concave programming problem, and the first order condition does not characterize the optimum. If we fix t_i's, however, an optimal p_i^o is determined by the first order condition.

$$\phi_i f(t_i) = \psi'(p_i^o) \text{ for } i = 1, 2$$

This is similar to the university-firm's optimal decision (2) except that we have the entire value of ϕ_i as benefit rather than $\frac{1}{2}\phi_i$. We can use the θ function defined in (4) to express p_i^o in terms of t_i; $p_i^o = \theta(t_i; 2\phi_i)$. If we plug this back into (7), the social planner's problem is to choose $(t_i)_{i=1}^{2}$ to maximize

$$W = \sum_{i=1}^{2} [\phi_i f(t_i) \theta(t_i; 2\phi_i) - \psi(\theta(t_i; 2\phi_i))] - c(t_1 + t_2).$$

The marginal benefit of increasing t_i can be defined as

$$\begin{aligned} MB_{t_i} &\equiv \frac{d}{dt_i} \{\phi_i f(t_i) \theta(t_i; 2\phi_i) - \psi(\theta(t_i; 2\phi_i))\} \\ &= \phi_i f'(t_i) \theta(t_i; 2\phi_i). \end{aligned}$$

Note that an indirect effect through the change of $\theta(t_i; 2\phi_i)$ will be 0 as p_i^o is optimally chosen given t_i.

Since our purpose is to illustrate that the equilibria are not generally Pareto ranked, we consider a symmetric case for simplicity, $\phi_1 = \phi_2$. We will compare the welfare between the extreme equilibrium with $t_2 = 0$ and the symmetric one with $t_1 = t_2$. We further assume, for expositional convenience, that c' and ψ' are linear. Then

$$MB_{t_i} = 4 \left\{ \frac{1}{2} \phi_i f'(t_i) \theta(t_i; \phi_i) \right\}$$

as $\theta(t_i; 2\phi_i) = 2\theta(t_i; \phi_i)$. Note that $\frac{1}{4} MB_{t_i}$ is the same as the LHS of equilibrium condition (5). In a symmetric equilibrium, as $t_1 = t_2 = t^S$, an equilibrium is achieved when $\frac{1}{4} MB_t = c'(2t^S)$. In an extreme equilibrium where $t_1 = t^E$, an equilibrium is achieved when $\frac{1}{4} MB_t = c'(t^E)$.

Fig 7 shows the determination of two types of equilibria and their welfare comparison. Two types of equilibria are the same in that t^S amount of time is initially invested on HK_1. A difference is made in the type of human capital the additional time is invested on. In an extreme equilibrium, additional time $t^E - t^S$ will be invested further on HK_1. In a symmetric equilibrium, additional time t^S will be invested on HK_2.

Figure 7: Welfare Comaparison - Extreme Equilibrium and Symmetric Equilibrium

(a)   (b)
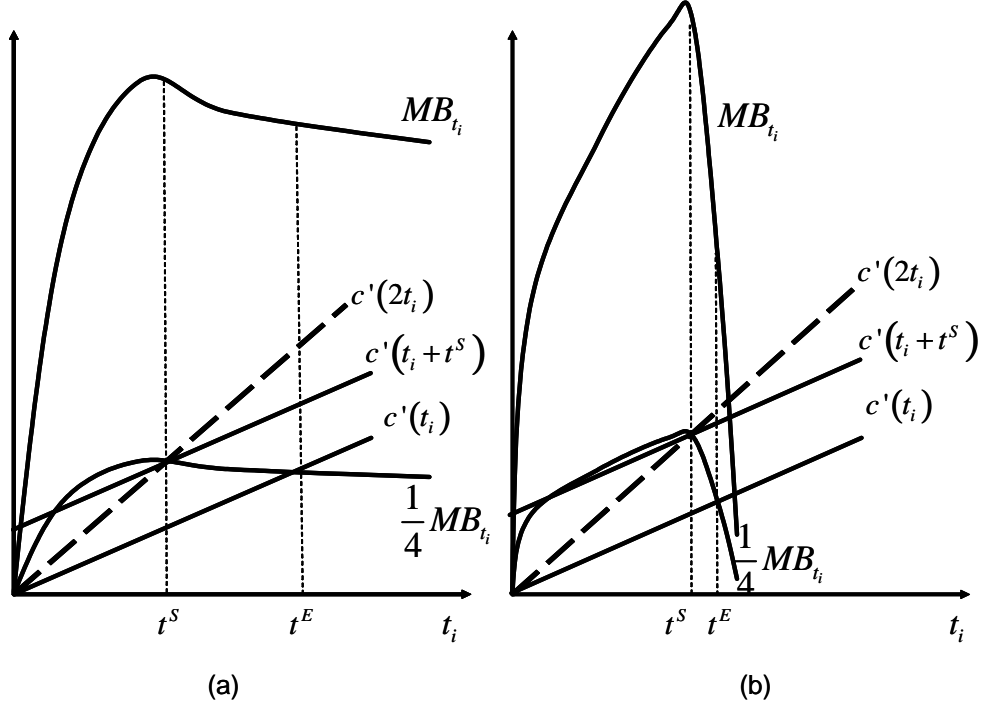
Welfare differences of two types of equilibrium come from differences in benefit and cost brought by this additional time investment. If it takes a high initial investment to build up the benefit of complementarity and the benefit does not diminish quickly as in panel (a), welfare gains of this additional time investment is larger in an extreme equilibrium. In the figure, the area under MB_t and above $c'(t)$ over $\left[t^S, t^E\right]$ is larger than that under MB_t and above $c'\left(t + t^S\right)$ over $\left[0, t^S\right]$. If the benefit of complementarity is quickly built up but diminishes quickly as in panel (b), a symmetric equilibrium will bring a larger welfare gain.

It is illustrated that there will be no generally-held Pareto ranking among equilibria. While the extreme equilibrium exploits the complementarity between the student-workers' and the university-firm's investments, the symmetric equilibrium can enjoy higher returns to investment. Which is Pareto better depends on the relative size of two benefits. Therefore, we cannot a priori tell whether U.S. or East Asian societies have a better arrangement for the utilization of human resources.

4   Discussion

In this section we will discuss the validity of our modeling choices and how essential they are to the result. We also discuss one possible historic and cultural factor which may affect which equilibrium

each society settles in: an educational ideal.

4.1 Discussions on Model Setting

4.1.1 Separate Development of Human Capital

Though, for analytical convenience, we assumed a separate development of two aspects of human capital, it is more realistic that a development of both aspects can interact with each other. That is, well-developed non-cognitive skills enhance a cognitive development and vice versa (Cunha and Heckman 2006, 2007). For example, personal perseverance and endurance can make students academically more successful. Therefore, if universities only consider students' academic performances, they do not only measure cognitive skills but also non-cognitive skills embodied in them. Students also have an incentive to invest in non-cognitive skills even when only academic performances are measured.

It is reasonable to assume, however, that an interaction of two aspects of human capital is more limited than a direct effect of investment specified for a certain skill. Time spent on academic activities will be more effective for advancing academic achievement than time spent for developing non-cognitive skills which will indirectly develop cognitive skills. Therefore, an investment in non-cognitive skills will be limited if measures of cognitive skills alone matter in university admissions. Allowing for a interaction between two skill developments would not change our main results much.

4.1.2 Non-negligible Investment Cost of Recognition

Some may argue that little investment is necessary for universities to recognize different aspects of human capital. More specifically, any assessment of non-cognitive skills such as extra-curricular activities and community involvement can be done easily if a university decides to do so.

Even though it may not be hard to require students to submit records of those extra-curricular activities, it might be difficult to read the capacity of students correctly from the records. Admission offices in U.S. institutions are usually staffed with officers specializing in reading and evaluating application packets. The median salary of these admission officers is around $80,000.[16] If an admission office is staffed with 10 to 12 professional experts, this is not a negligible amount of investment.

4.1.3 No Limit on Class Size

We assume there are two different positions in a university-firm and there is no limit in the number of positions. In actual university admissions, however, there is a limited class size and both aspects

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[16] www.salary.com

of human capital can be considered at the same time. It would be more realistic if we assume the limited positions in a university and admission decisions based on the evaluation of both aspects.

However, the current model setting captures a university's decision problem fairly well. As a class size is limited, it will be very costly to fill the class based on relatively inaccurate information. The cost of admitting ill-equipped students in this model captures such a cost caused by the limited class size. Admission probability will increase if students are evaluated highly in both aspects of human capital. Being hired in both positions at the same time in this model captures that increase in admission probability. Therefore, this model setting can be easily translated into admissions based on an evaluation of both aspects with a limited class size, and the main results will hold if we change the model setting in that way.

4.2 Why does each society end up in the present equilibrium?

Models of multiple equilibria can explain how different arrangements can be maintained as economic fundamentals become similar, but do not offer an explanation why a certain equilibrium is chosen for each society. This paper is no exception. In this section, we will propose some possible historic origins which may help to explain how the current arrangement is reached.

In East Asian societies, it is a very long tradition to select an elite group through an examination testing cognitive skills only. Appointment as a public official is an important route to joining the ruling elite, and these public officials are selected through such an exam. In China, the "imperial examination" started in Sui dynasty (589-618) and lasted for 1,300 years until 1905 (Miyazaki 1976). The modern examination system for hiring civil servants is believed to indirectly evolve from the imperial exam. This also affected surrounding countries. For example, in Korea, the *gwageo*, a similar national civil service exam, first started in 788 and continued until 1894 (Lee 1981). It is also believed that a modern day civil service exam originated from this. Such a long tradition of selection based on an exam could have affected the modern way of human capital evaluation.

In the U.S., it seems that a cultural and educational ideal of elite Protestants played an important role in the current shape of admissions process.[17] The WASP (White Anglo-Saxon Protestant) upper class, which was a leading group in the late 19th century, emphasized other conditions as well as an intellectual development for a desirable human. Aims of elite boarding schools, which were major suppliers of students to leading private universities, were to "cultivate manly, Christian character, having regard to moral and physical as well as intellectual development..." Though the passing of an entrance exam was the only requirement for an admission to elite universities at that time, it seems that other characters were taken for granted through the secondary education. The Rhodes scholarships, the oldest international educational fellowships which started in 1902 and are

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[17] Current discussions on the U.S. are heavily indebted to Karabel (2005).

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still in action, explicitly show this ideal in its four selection criteria: scholarstic attainments, energy shown in sports activity, character, and morality.[18]

As secondary education expanded in 1920s, elite universities started to restrict the size of freshmen class - birth of selective admissions. Rather than increasing academic standards of entrance exams, they chose to turn to the cultural and educational ideal of elite Protestants, which was embodied in the Rhodes criteria.[19] Subjective criteria such as character came to play an important role in admissions. While the relative importance of objective academic criterion and subjective personal one may have been changing since, the basic structure of admissions standards has been maintained.

5 Empirical Relevance

In this section, we will discuss empirical implications of the paper and evaluate the empirical relevance of our argument by actually testing one implication.

5.1 Implications

5.1.1 Effect of Non-cognitive Skills on Labor Market Outcome

Our model suggests that effects of non-cognitive skills on labor market outcomes may vary among countries. There have been some studies showing a positive impact of non-cognitive skills on labor market outcomes. These studies mostly used U.S. data. In East Asian countries, however, as non-cognitive skills are not recognized as well as in the U.S., this effect would be smaller.

We are not arguing that the effect is small in every country where academic achievement is the only admissions standard. The U.S. is a quite special case in that universities explicitly consider measures of non-cognitive skills in admissions. Even if a university considers only academic measures, non-cognitive skills can be recognized in the labor market. Universities may not explicitly consider them because it is just too costly to do that. To induce a development of non-cognitive skills, however, universities can reduce the importance of academic measures in admissions. That is, academic achievement can be evaluated as a certain minimum requirement, or a small distinction of academic achievement may not be recognized. In this way, universities can induce an investment in non-cognitive skills which are not easily measured.[20]

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[18] Rhodes Brochure at http://www.rhodesscholar.org/info.

[19] Karabel (2005) also argues that this change was to restrict the growing Jewish population among freshmen.

[20] According to Holmstrom and Milgrom (1991), agents with multi-tasks, some of which have well-measured performances while others have no clear performance measures available, should be given a muted incentive scheme. If a strong incentive scheme is given to well-measured tasks, this will reduce the performance in other tasks. By the same logic, reducing the importance of acadmic measures can induce more investment in non-cognitive skills.

5.1.2 Relationship between Labor Productivity and Cognitive Skills

As internationally comparable test scores are developed and released, there have been studies that relate these test scores to a country's economic performances. Our model suggests that this study should also control for the time spent on non-cognitive skill development since these test scores mainly measure cognitive skills. If a country has a high average score with much time spent on academic activities, this country must have invested relatively less on non-cognitive skills. Therefore, this country's economic performance would be less stellar compared with a country with a similar test score but less time spent on academic activities.

Our model also proposes a cautionary note for an implication of these studies. Cognitive skills are important in economic performances and developing countries need to promote them. However, it is not warranted that they should invest in these cognitive skills at any cost. An emphasis on cognitive skills cannot but lead to a relative neglect of other skills. A country has to weigh this cost carefully in the development strategy of cognitive skills. Especially for East Asian countries which put an enough emphasis on cognitive skills, it might be necessary to pay less attention to them.

5.2 Test

Here we provide empirical evidence supporting an argument that an investment in non-cognitive human capital matters in a country's economic performance and its implications for empirical analyses. Given a trade-off between cognitive and non-cognitive skill investments, an implication of the importance of non-cognitive human capital for an empirical analysis is that an investment in non-cognitive skills is an omitted variable in conventional growth regressions. An omission of an important variable yields a bias in an OLS estimate of the effect of cognitive skills. To examine our claims, we estimate the following model of economic performance or growth regressions that considers the quality of both cognitive and non-cognitive human capital:

$$y_i = \beta_0 + \beta_1 C_i + \beta_2 NC_i + \beta_3 X_i + u_i$$

where y_i is a measure of country i's economic performance; C_i is i's level of cognitive skills proxied by the average score of an international standardized test; NC_i is i's level of an investment in non-cognitive skills; X_i is a vector of i's observable characteristics; and u_i is the error term.

The current paper argues that $\beta_2 > 0$ and that an OLS estimate for β_1 may be subject to a negative bias due to $Cov(C_i, NC_i) < 0$ if NC_i is not controlled for in the regression. Conventional growth regressions ignore a potential positive effect of non-cognitive skills on a country's economic performance, thus understating an impact of cognitive skills on it. If NC_i is included as an extra explanatory variable, we expect an OLS estimate for β_1 to increase and that for β_2 to be significantly positive.

5.2.1 Data

In the analysis that follows, y_i is measured by either a country's contemporary level of output per worker, total factor productivity, or average growth rate of GDP per capita from 1960 to 2000, following conventional models. C_i is proxied by a country's average math score of an international test and NC_i by a country's average share of students' daily time devoted to activities related to non-cognitive skills. Depending on the specification, X_i includes GDP per capita in 1960, years of schooling in 1960 and 1988 and a measure of physical capital stocks in 1988.

These variables are drawn from three separate sources. Information on the average growth rate of GDP per capita from 1960 to 2000, GDP per capita in 1960, and years of schooling in 1960 is extracted from Jamison et al. (2006). The contemporary level of output per worker ($log(Y/L)$), the total factor productivity ($log(TFP)$), the capital-output ratio ($(\alpha/(1-\alpha)) \cdot \log(K/Y)$) and years of schooling in 1988 are drawn from Hall and Jones (1999). A country's average math score and average share of daily time on activities related to non-cognitive skills are extracted from the Third International Mathematics and Science Study (TIMSS), 1995, for the 13-year-old students (Population 2) (Gonzalez and Smith, 1997).

To the best of our knowledge, TIMSS 1995 is the only international data source that can serve our purpose, as it contains information on both a country's average score of cognitive tests and a share of activities related to non-cognitive skills. Other international data sets such as the Programme for International Student Assessment (PISA) of the OECD and the Progress in International Reading Literacy Study (PIRLS) provide information on a country's average scores of cognitive tests but not a measure of an investment in non-cognitive skills. Based on the answers to a student's daily time use in TIMSS 1995, we classify 'playing sports' and 'playing or talking with friends outside of school' as activities related to non-cognitive skills. These non-cognitive skill activities exclude miscellaneous activities such as 'watching TVs and videos', 'playing computer games', and 'working at a paid job' as well as academic activities such as 'studying mathematics or science after school', 'taking extra lesson/cramming school in mathematics or science', etc. In the analysis a share of daily hours spent on the non-cognitive skill activities out of daily total used time is used as a measure of an investment in non-cognitive skills.

Table 2 shows correlation coefficients between variables for 30 countries that have valid information for subsequent analysis.[21] Two observations are noteworthy. First, the average math score of a country—a measure of the quality of cognitive human capital—has a positive correlation with the average growth rate (0.548), $log(Y/L)$ (0.399) and $log(TFP)$ (0.302) but it has a negative correlation with the share of activities related to non-cognitive skills (-0.063). Second, the share

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[21]These 30 countries are as follows: Australia, Austria, Belgium, Canada, Colombia, Cyprus, Denmark, France, West Germany, Greece, Hong Kong, Hungary, Iceland, Iran, Ireland, Israel, Japan, South Korea, Netherlands, New zealand, Norway, Portugal, Romania, Singapore, South africa, Spain, Sweden, Switzerland, Thailand, U.S.A.

Table 2: Correlation Coefficients between Variables (N=30)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Avg growth rate (1960-2000)	1.000						
(2) log (Y/L)	-0.171	1.000					
(3) log (Total Factor Productivity)	0.017	0.861	1.000				
(4) Avg math score/100 in 1995	0.548	0.399	0.302	1.000			
(5) Share of activities related to non-cognitive skills	-0.502	0.620	0.396	-0.063	1.000		
(6) Years of schooling in 1988	-0.276	0.607	0.166	0.341	0.483	1.000	
(7) Capital-output ratio in 1988	-0.445	0.471	0.113	0.095	0.585	0.446	1.000

of activities related to non-cognitive skills has a positive correlation with $log(Y/L)$ (0.620) and $log(TFP)$ (0.396), while having a negative correlation with the average growth rate (-0.502). As suggested in the paper, a negative correlation between the average math score and the share of non-cognitive skill activities implies that conventional cross-country regressions that control for the quality of cognitive human capital alone are likely to be subject to a negative bias. To avoid such a bias, the regressions need to control also for an investment in non-cognitive skills that increases a country's economic performance.

5.2.2 Results

Table 3 presents empirical evidence supporting such possibilities. In column (1), following conventional cross-country regressions, $log(Y/L)$ is regressed against measures of the quality of cognitive human capital, the quantity of general human capital (years of schooling) and the capital-output ratio as defined in Hall and Jones (1999). Such a specification is based on a decomposition of output per worker into educational attainment, the capital-output ratio and total factor productivity suggested in Hall and Jones (1999). The average math score (0.151) is positively associated with $log(Y/L)$, although the estimate is not statistically significant; the years of schooling (0.113) is also positively and statistically significantly associated with $log(Y/L)$; the capital-output ratio (0.609) is positively associated with $log(Y/L)$, although insignificant. If the share of non-cognitive skill activities is added as in column (2), the degree of association between the average math score and $log(Y/L)$ (0.246) becomes about 1.6 times as large. Although the coefficient of the average math score is significant only at the 0.08 level (partly due to a small sample), an increase in the size of the coefficient suggests that there is an omitted variable in the conventional cross-country regression as in column (1). As expected, the estimate for the share of non-cognitive skill activities

Table 3: Cross-country Regression Results by OLS

Dependent variables:	Mean (S.D.)	log (Y/L)		log (TFP)		Avg growth rate (1960-2000)	
		(1)	(2)	(3)	(4)	(5)	(6)
Avg math score/100 in 1995	5.014	0.151	0.246*	0.157*	0.168	1.328*	1.445*
	(0.572)	(0.106)	(0.135)	(0.096)	(0.111)	(0.169)	(0.189)
Share of activities related	0.296		3.206*		1.791*		3.642
to non-cognitive skills	(0.076)		(1.223)		(0.941)		(2.415)
Years of schooling in 1988	7.797	0.113*	0.073*				
	(2.315)	(0.038)	(0.040)				
Capital-output ratio in 1988	0.471	0.609	-0.272				
	(0.121)	(0.796)	(0.900)				
GDP per capita in 1960	7891.0					0.000*	0.000*
	(4358.2)					(0.000)	(0.000)
Years of schooling in 1960	6.984					0.013	-0.031
	(2.621)					(0.104)	(0.100)
Constant	-	7.897*	7.189*	7.667*	7.085*	-2.093*	-3.191*
	-	(0.546)	(0.717)	(0.473)	(0.665)	(0.934)	(1.139)
R-squared		0.370	0.480	0.040	0.130	0.728	0.744
Sample size		32	32	32	32	28	28

Notes: Standard errors are in parentheses. * indicates that the estimate is significant at the 0.1 level.

is significantly positive. A 10 percent increase in the share of non-cognitive activities from the sample mean (i.e., from 0.296 to 0.326) increases a country's output per worker by approximately 9.6 percent.

A similar but less dramatic pattern arises if total factor productivity of a country, which is a measure of productivity that is more closely related with a country's quality of human capital according Hall and Jones (1999), is considered as a dependent variable in columns (3) and (4). When $log(TFP)$ is regressed against the average math score alone in column (3), the average math score (0.157) is positively associated with $log(TFP)$, the coefficient being significantly different from zero at the 0.1 level. In column (3), the years of schooling and the capital-output ratio, which are included in columns (1) and (2), are not controlled for because both of them have been already considered in generating $log(TFP)$ by Hall and Jones (1999).[22] If the share of non-cognitive skill

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[22]Including the years of schooling and the capital-output ratio in columns (3) and (4) fails to yield qualitatively different results than those presented in Table 3. If they are controlled for as explanatory variables, the coefficient of the average math score is 0.131 (s.e. 0.112) for column (3), and 0.223 (s.e. 0.140) for column (4), while insignificant

activities is added as in column (4), the degree of association between the average math score and $log(TFP)$ increases to 0.168, which is significantly different from zero at the 0.14 level. Moreover, the estimate for the share of non-cognitive skill activities is significantly positive. Therefore cross-country regressions that control for the quality of cognitive human capital alone but omit an investment in non-cognitive human capital understate the true impact of cognitive human capital on a country's productivity. Activities related to non-cognitive skills positively affect a country's productivity. A 10 percent increase in the share of non-cognitive activities from the sample mean (i.e., from 0.296 to 0.326) increases a country's total factor productivity by approximately 5.4 percent.

Discussing why the U.S. has been showing robust economic performances while it has never done well in international cognitive assessments, Hanushek and Woessmann (2008) propose the following three factors as potential explanations: openness and fluidity of its markets, rapid quantitative expansion of education, and efficient higher education. The finding of the current paper that non-cognitive skills matter a country's productivity adds one more reason why the U.S. is exceptional to their explanations, shedding light on potential determinants of a country's economic performance. Among 32 countries considered in our empirical analysis, the U.S. ranks relatively high at the 12nd place in the share of non-cognitive skill activities while ranking at the 24th in the average math score.

When the average growth rate of per capita GDP between 1960 and 2000 is employed as a dependent variable as in columns (5) and (6), the share of non-cognitive skill activities is also found to have a positive effect, while the estimate is significant at the 0.145 level. As expected, the estimate for the average math score increases as the share of non-cognitive skill activities is added as an explanatory variable, suggesting that the true impact of cognitive skill on growth is likely to be understated if an investment in non-cognitive human capital is omitted. While specifications based on the growth rate of output per capita as in columns (5) and (6) are more popular in the growth literature (Mankiw et al, 1992; Barro and Sala-i-Martin, 1992), we put more weight on the estimates of columns (2) and (4). The empirical evidence for this paper is likely to be better illustrated by specifications based on the *level* of the output per worker or the total factor productivity. If the growth rate of the output per worker is used as an outcome variable, it is in general difficult to distinguish the role of capital accumulation from that of productivity enhancement in economic performance. Both cognitive and non-cognitive human capitals, however, are likely to be more closely related with productivity enhancement than with capital accumulation.

in both specifications.

6 Conclusion

This paper introduced a model of human capital investment and evaluation with multiple aspects of human capital. When there is an interaction between investment and evaluation, there can be multiple equilibria. Therefore, with the same economic environment, one society emphasizes only one aspect of human capital while other society emphasizes both aspects.

The model can accommodate the discrepancies in university admissions standards between the U.S. and East Asian countries. The model predicted that more time investment in academic activities will go together with more emphasis on academic evaluation, and that even time investment on academic and non-cognitive skill activities with even emphasis on both aspects. This is consistent with what we observe in East Asian countries and the U.S.

The model also has empirical implications in the relationship between cognitive skills and economic performances. Empirical tests of this implication reasonably support the model's empirical relevance.

References

[1] Atkinson, Richard C., "Achievement Versus Aptitude Tests in College Admissions", Issues in Science and Technology, 2001.

[2] Christopher, Avery, Andrew Fairbanks, and Richard Zeckhauser, "What Worms for Early Bird: Early Admissions at Elite Colleges." John F. Kennedy School of Government Faculty Research Working Paper Series, RWP 01-049, 2001.

[3] _____, The Early Admissions Game: Joining the Elite, Cambridge: Harvard University Press, 2003

[4] Barro, Robert J. and Xavier Sala-i-Martin, "Convergence." Journal of Political Economy, 1992, 100(2), pp.223-51.

[5] Berg Dale, Stacy and Alan B. Krueger, "Estimating the Payoff to Attending a More Selective College: An Application of Selection on Observables and Unobservables." Quarterly Journal of Economics, 2002, 117(4), pp.1491-527.

[6] Borghans, Lex, Angela Lee Duckworth, James J. Heckman, and Bas ter Weel, "The Economics and Psychology of Personality Traits." Journal of Human Resources, 2008, 43(4), pp.972-1059.

[7] Bowen, William G. and Derek Bok, The Shape of the River: Long-Term Consequences of Considering Race in College and University Admissions, Princeton: Princeton University Press, 1998.

[8] Coate, Stephen and Glenn C. Loury, "Will Affirmative-Action Policies Eliminate Negative Stereotypes?" American Economic Review, 1993, 83(5), pp. 1220-40.

[9] Cunha, Flavio and James J. Heckman, "The Technology of Skill Formation." IZA Discussion Paper Series No. 2550, 2007.

[10] _____, "Formulating, Identifying and Estimating the Technology of Cognitive and Noncognitive Skill Formation." Journal of Human Resources, 2008, 43(4), pp.738-82.

[11] Diamond, Peter A. "Aggregate Demand Management in Search Equilibrium." Journal of Political Economy, 1982, 90(5), pp.881-94.

[12] Fang, Hanming, "Disentangling the College Wage Premium: Estimating a Model with Endogenous Education Choices." International Economic Review, 2006, 47(4), pp.1151-85.

[13] Gale, David and Lloyd Sharpley, "College Admissions and the Stability of Marriage", American Mathematical Monthly, 1962, 69, pp.9-15.

[14] Gonzalez, E.J., Smith, T.A., User guide for the TIMSS international database: Primary and middle school years, Boston College, MA, TIMSS International Study Center, 1997.

[15] Hall, R., Jones, C., "Why Do Some Countries Produce So Much More Output Per Worker Than Others?", Quarterly Journal of Economics, 1997, 114(1), pp. 83-116.

[16] Hanushek, Eric and Dennis D. Kimko, "Schooling, Labor-Force Quality, and the Growth of Nations." American Economic Review, 2000, 90(5), pp. 1184-1208.

[17] Hanushek, Eric A. and Ludger Woessmann, "The Role of Cognitive Skills in Economic Development." Journal of Economic Literature, 2008, 46(3), pp.607-68.

[18] Heckman, James J., Jora Stixrud, and Sergio Urzua, "The Effect of Cognitive and Noncognitive Abilities on Labor Market Outcomes and Social Behavior." Journal of Labor Economics, 2006, 24(3), pp.411-81.

[19] Holmstrom, Bengt and Paul Milgrom, "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design." Journal of Law, Economics, and Organization, 1991, 7(Sp), pp.24-52.

[20] Jamison, E.A., Jamison, D., Hanushek, E., The Effects of Education Quality on Income Growth and Mortality Decline, Working Paper No.12652, Cambridge, MA: National Bureau of Economic Research. 2006.

[21] Juster, Thomas F. and Frank P. Stafford, "The Allocation of Time: Empirical Findings, Behavioral Models, and Problems of Measurement." Journal of Economic Literature, 1991, 29(2), pp.471-522.

[22] Karabel, Jerome, The Chosen: The Hidden History of Admission and Exclusion at Harvard, Yale, and Princeton, Boston, MA: Houghton Mifflin, 2005.

[23] Lee, Ki-baik, A New History of Korea, Cambridge: Harvard University Press, 1981.

[24] Lee, Sam-Ho, "Jumping the Curse: Early Contracting with Private Information in University Admissions", International Economic Review, 2009, 50(1), pp.1-38.

[25] Lee, Sanghoon, "The Timing of Signalling: To Study in High School or in College?" International Economic Review, 2007, 48(3), pp.785-807.

[26] Mailath, George J., Larry Samuelson, and Avner Shaked, "Endogenous Inequality in Integrated Labor Markets with Two-Sided Search." American Economic Review, 2000, 90(1), pp.46-72

[27] Mankiw, N. Gregory, David Romer and David Weil, "A Contribution to the Empirics of Economic Growth." Quarterly Journal of Economics, 1992, 107(2), pp.407-37.

[28] Miyazaki, Ichisada, The China's Examination Hell: The Civil Service Examination of Imperial China, New York: Weatherhill, 1976.

[29] Postlewaite, Andrew and Dan Silverman, "Social Isolation and Inequality." Journal of Economic Inequality, 2005, 3, pp.243-262.

[30] Stevenson, Betsy, "Beyond the Classroom: Using Title IX to Measure the Return to High School Sports." CESIFO Working Paper No. 2959, 2010.

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