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Trade and Divergence in Education Systems

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Trade and Divergence in Education Systems

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Abstract

This paper presents a theory on the endogenous choice of a country's education policy and the two-way causal relationship between trade and education systems. The setting of a country's education system determines its talent distribution and comparative advantage in trade; the possibility of trade by raising the returns to the sector of comparative advantage in turn induces countries to further differentiate their education systems and reinforces the initial pattern of comparative advantage. Specifically, the Nash equilibrium choice of education systems by two countries interacting strategically are necessarily more divergent than their autarky choices, although the difference is still less than what is socially optimal for the world. We provide some preliminary empirical evidence on the relationship between education, talent distribution, and trade.

JEL Classification: F16, I20, J24.

Key Words: Education System, Talent Distribution, Comparative Advantage, Trade Pattern.

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1 Introduction

In this era of globalized knowledge economy, the education system, by shaping a country's human capital, may exert significant influences on its comparative advantages in international trade. And conversely, a country's trade pattern and intensity may affect how its education system is run. Such interactions between education and trade could be seen in recurrent reviews of education policies by nations across the world. In the US, for example, the National Commission on Excellence in Education (1983) claimed in an influential report that America is at risk: "The risk is not only that the Japanese make automobiles more efficiently than Americans . . . , or that American machine tools . . . are being displaced by German products. It is also that these developments signify a redistribution of trained capability throughout the globe. . . . If only to keep and improve on the slim competitive edge we still retain in world markets, we must dedicate ourselves to the reform of our educational system ..." ¹

In spite of the clear importance and urgency of educational reform in its role of affecting countries' comparative advantages, we are not aware of any formal analysis in the economics literature to shed light on this matter. This paper makes a first attempt at providing a theory on the two-way interactions between education policies and trade. In particular, we show that any initial difference in education policies across countries that contributes to countries' comparative advantages will be further enlarged when countries move from autarky to trade. The intuition is that international trade increases the returns to the sector of comparative advantage, and thus induces countries to further differentiate their education systems in order to maximize gains from specialization. As a result, a small difference in initial education systems across countries, possibly due to historical or cultural variation, will be further amplified by the increase in international trade.

In this paper, we focus on an important characterization of a country's education system, which is the degree of centralization or homogenization imposed on the curriculum, and its effect on a country's talent distribution. A more homogeneous structure of curricula across schools improves

¹For related discussions on the US education, see Schaub and Baker (1991), Westbury (1992), Bracey (1996), Hanushek (2002), and Dillon (2007), among others. For recent educational reforms in other countries, see for example Takayama (2007) on Japan, Mok (2005) on East Asia, and Green (1999) for general discussions on the effects of globalization on education across countries.

the likelihood that the same set of subjects are taught, and delivered in similar manners to the students; as a result, students are more likely to acquire a common set of skills. This type of education system is often associated with a centralized curriculum council that sets and enforces a uniform curriculum via textbooks, instructional guide to teachers, curriculum evaluation, or national standardized tests, as is evident in Japan and some East Asian countries. The resulting pressures to conform with the uniform standards in terms of education outputs, however, leave relatively little room for individual explorations and hence could push the more-talented students toward the mean as well as the lower-ability students. In contrast, if schools/teachers do not need to follow a standardized set of curricula or performance targets, this tends to introduce more variation in student performance, as students have more freedom to pursue their individual interests and realize their potentials under a flexible curriculum; without the necessary discipline, however, the less-talented students may fail to acquire the basic set of skills. This approach is often carried out in a decentralized education system as is exemplified by the US system. Thus, relatively speaking, the Japanese style of education system promotes homogeneity in the distribution of skills, while the US education system leads to more diversity. The education systems in other countries, different in their orientation toward these two approaches, generally fall in between these two extremes (Cummings 1999).

We show in theory that by altering the resulting talent distribution, different educational approaches will lead to differences in comparative advantage and trade structure in countries with otherwise identical economic constraints. Specifically, the decentralized education system in the US tends to promote talent diversity in its work force, which enhances the productivity of industries that benefit from worker skill heterogeneity, e.g., software and movie; in contrast, with a centralized education system, Japanese work force tends to be more homogenous in their skills, which increases the productivity of industries characterized by long and complex production processes, e.g., automobile and machinery. It then follows that countries with more decentralized education systems will have a comparative advantage in the software-type industries and countries with more centralized education systems a comparative advantage in the automobile-type industries.

Given the effects of education system on production and a country's comparative advantage, we

show that the endogenous choice of education system across countries will exhibit more divergence under trade than under autarky. This is because the equilibrium price with trade will fall in between autarky prices and thus strengthen the incentives of a country to specialize more in the sector of its comparative advantage, not only via automatic resource reallocation across sectors with a given work force, but also through active adjustment in education policies to reshape the composition of its work force and the position of its production possibility frontier.

In particular, we identify the choice of education system under autarky by individual countries who may differ in their costs of implementing homogeneous curricula, but are otherwise identical in economic constraints and initial talent distributions. We then characterize the choice of education system under trade that is socially optimal for the world as a whole. This is compared with the noncooperative choice in the Nash equilibrium where each country maximizes its own welfare taking into account the terms-of-trade effect of its education policies. It is shown that the difference in education systems across countries under trade is larger than under autarky. However, the cross-country difference in education systems under the Nash equilibrium is less than what is socially optimal for the world. The intuition is that the incentive to specialize through more divergent education systems is weakened in each country by the accompanying terms-of-trade loss, which on the other hand cancels out for all countries in the world welfare's calculation.

We conduct some preliminary empirical analysis to demonstrate our theory's empirical relevance. Based on the Trends in International Mathematics and Science Study (TIMSS) dataset, which contains information on student performance and curriculum structure, we propose some measures of curriculum centralization to capture the theory's characterization of national education systems in terms of the degree of homogenization imposed on students' skill formation. We show that in the sample of OECD countries, a more centralized curriculum structure is indeed associated with a lower skill diversity, and the relationship is statistically significant and consistent across different years of study. Furthermore, as the trade intensity between a pair of countries increases, their difference in curriculum centralization also tends to increase. This is consistent with our theoretical prediction that trade tends to reinforce countries' initial differences in education systems. However, given the caveats that will be noted in the empirical section, more research into

the empirical measures of education systems is needed to provide more persuasive conclusions.

Viewed from a broader perspective, this paper contributes to the literature in two ways: First, it demonstrates the possibility of education policy as a new source of comparative advantage in trade, and second, it emphasizes how trade can in turn affect a country's institutions such as education systems. To our knowledge, this endogenous determination of both education system and trade pattern as an equilibrium outcome has not been examined in the literature.

This paper is closely related to the literature on human capital (talent) and trade. This literature generally falls into two branches: The first branch takes talent distribution as given and analyzes its effect on comparative advantage and trade pattern (see Grossman and Maggi 2000 for example), while the second branch studies the effect of trade on the *stock* of human capital using fixed human capital production functions (see Findlay and Kierzkowski 1983, and Bond et al. 2003 for example). Our paper integrates these two strands of literature by explicitly modeling the triangular relationship between education policy, human capital and trade. The introduction of education policy in our model influences the human capital formation process and determines the *composition* of human capital in a country. The resulting talent distribution then affects a country's comparative advantage and trade pattern (as in the first literature). When countries endogenously choose their education policies relative to their trading partners to maximize social welfare, there are feedback effects of trade on human capital (as in the second literature). This paper thus provides new insights into the important role of education policy in affecting the relationship between human capital and trade.²

²The first branch of the literature starts with the pioneering work by Grossman and Maggi (2000), who show that between two trading countries, the one with a more diverse (alternatively, homogeneous) talent pool tends to exhibit a comparative advantage in producing goods or services with a submodular (alternatively, supermodular) technology. This may account for the trade pattern between the US and Japan, where the US has more diverse talents and exports software, while Japan has more homogeneous talents and exports cars. The effect of talent distribution on trade is also examined by other studies based on alternative mechanisms including the role of costly monitoring of workers (Grossman 2004), the implications of two-dimensional skill heterogeneity (Ohnsorge and Treffer 2007), the trade of high-tech versus primary product (Bougheas and Riezman 2007), and the empirical evidence about the effect of skill dispersion on trade patterns (Bombardini et al. 2009). The second branch of the literature includes Findlay and Kierzkowski (1983) and Bond et al. (2003) among others. In Findlay and Kierzkowski (1983), it is observed that trade will accentuate the autarky difference between countries in skilled-unskilled labor proportions. This is similar in spirit to our result that the initial pattern of comparative advantage is sustained and the difference in the human capital composition between countries is augmented by trade. By allowing endogenous formation of both physical and human capital, Bond et al. (2003) show that the ranking of countries' relative factor abundance and trade pattern may actually persist or reverse over time. Such indeterminacy is thus in contrast with the above result.

In another strand of literature, several papers also explicitly link education with trade but differ from us in the issues and the specific education policies studied. Kim and Kim (2000) assume that school education enhances general human capital versus industry-specific skills, which together with international trade allows workers to move easily to the fastest-growing industry and hence facilitates economic growth. In an oligarchy society where landed elites have more political power, Falkinger and Grossmann (2005) show that public education investment conducive to industrialization is typically lower in an open economy than in autarky; this is similar in spirit to our result that an open economy may adopt a more extreme education approach than in autarky. Bougheas et al. (2009) also analyze the possible effect of trade on a country's education policy. They formulate the education policy, however, as a choice by a small open economy of whether to move up or down the skill chain, taking the terms of trade as given; this is in contrast with our focus on the education policy's role in affecting the diversity of human capital and the optimal allocation of talent across sectors. More importantly, our analysis takes into account the consequence of education policies on the equilibrium trade prices and patterns, which enables us to study the interactions of education policies across countries and their endogenous divergence.

The current paper also connects with the economics literature on education that examines how different education regimes (public versus private, ability tracking versus ability pooling) affect the dispersion of skills and aggregate output *in closed economies* (see for example Bénabou 1996, Epple and Romano 1998, Fernández and Rogerson 1998, Takii and Tanaka 2009). An innovative feature of the current paper in comparison to this literature is that the education regimes are endogenously determined *across countries* and inherently linked with international trade. The paper's focus on the degree of curriculum centralization in an education system also highlights an important dimension distinct from the above literature's typical emphasis on school financing methods.

The education literature has only recently begun to assess the implications of globalization on education policies (Green 1997, Burbules and Torres 2000, Mok 2005). Though "there is considerable convergence at the level of policy rhetoric and general policy objectives, there is less evidence of any systematic convergence at the level of structures and processes in different countries" (Green 1999). This is consistent with our finding in this paper that differences in education systems across

countries may be a persistent pattern reinforced by trade. To our knowledge, this result is new to the education-related literature and may provide a fresh perspective on how education policies are formed.

This paper is organized as follows. The elements of the model are described in Section 2. The endogenous choice of education system is analyzed in Section 3. We take our model to data and present some preliminary empirical evidence in Section 4. Section 5 discusses modeling choices and possible extensions. Section 6 concludes.

2 The Basic Model

2.1 The Education System

Suppose there is a unit measure of a continuum of pupils indexed by i , whose innate abilities a_{i0} are not individually observable, but follow a distribution $G(\cdot)$ with support $[a_{l0}, a_{h0}] \subset (0, +\infty)$. All pupils have to go through an education system that may possibly change their initial skills. The education system is characterized by a parameter $\delta \in [0, 1]$, which indicates the degree of curriculum centralization/homogeneity imposed on each student. Specifically, a pupil with an innate ability a_{i0} will acquire a skill level a_i at graduation such that

$$(1) \quad a_i = (1 - \delta)a_{i0} + \delta a_m,$$

where $a_m = \int_{a_{l0}}^{a_{h0}} a_{i0} dG(a_{i0})$ is the average ability of the cohort. Thus, an education system with a high δ will push all students' skills to the middle and reduce the skill diversity, while keeping the mean ability unchanged.

Each pupil's adulthood skill a_i is publicly observed with a support $[a_l, a_h] \subseteq [a_{l0}, a_{h0}]$, where $a_h - a_l = (1 - \delta)(a_{h0} - a_{l0})$, and its corresponding distribution function is $G(\frac{a_i - \delta a_m}{1 - \delta}) \equiv F(a_i; \delta)$. We will often write the adulthood distribution as $F(a_i)$ to simplify presentations, bearing in mind that it depends on δ . The adults are ranked according to their abilities such that $a_i \leq a_j$ for $i < j$.

We can generalize (1) to allow an additional benefit $e > 0$ of education that is independent of

the curriculum centralization, that is, $a_i = (1 - \delta)a_{i0} + \delta a_m + e$. It is straightforward to verify that the subsequent results will not be affected. We take the functional form (1) henceforth to focus on the education system's impact on talent diversity and abstract from its potentially positive effect on human capital accumulation.

This simple model of education attempts to capture the necessary tension between equipping all students with a common set of knowledge versus promoting talent diversity. The former goal is usually better achieved with a more standardized set of curricula, where students have to go through the same subjects, and numerous exercises and exams that test whether they have met required standards before they can go to the next level of study. The time and efforts committed to following the same curriculum and activities, however, often discourage students from exploring and acquiring new knowledge in their own ways, and hence may reduce the creativity component of human capital (Mayer et al. 1991). The opposite is true for pursuing the second goal, where flexible curricula and lenient standards are set to leave more freedom for individual exploration and hence may preserve more talent diversity. Education systems may vary across countries in their orientation toward these two goals. Among industrial countries, Japan and the US are arguably the two prominent examples at the opposite ends of the spectrum in terms of curriculum centralization.

The innate or initial abilities a_{i0} are taken to be unobservable to educators or even to the student herself/himself. This is to underlie the difficulty of the education system to correctly evaluate each student's true talent and to tailor the teaching method δ according to each individual's ability. For example, if the initial abilities were fully observable, the education resources would be best utilized to raise the skills of the less-talented students with a more disciplined education method but those of the more-talented students with a more flexible curriculum. Alternatively, if the innate abilities a_{i0} were known to the students, a menu of education methods could be offered such that students self select into different schemes. The assumption of unobservability of initial abilities highlights the inevitable trade-off of positive and negative effects of choosing a particular education style on the human capital of a country.

2.2 The Economy

Technology. We lay out the structure of the economy below and demonstrate the implications of given education systems on production and trade patterns. The results are consistent with the existing work in the literature with exogenous talent distributions.³ Our main departure from the literature starts in Section 3 where we explicitly analyze the choice of education system.

There are two industries in the economy. In the automobile industry, the production technology is supermodular with decreasing returns to overall talent,⁴

$$y_A = [a(1)^\alpha + a(2)^\alpha + \dots + a(n)^\alpha]^{\theta/\alpha}, \quad 0 < \alpha < \theta < 1$$

where n is the number of tasks required. The supermodularity of the auto production is reflected by the fact that $\partial^2 y_A / \partial a(j) \partial a(j') > 0$, for all $j \neq j' \in \{1, 2, \dots, n\}$ and the decreasing returns to overall talent by the fact that $\theta < 1$. In the other industry, the software industry, the output is completely reflective of individual talent,

$$y_S = a^\gamma, \quad \gamma > 1$$

and exhibits increasing returns to the talent. Let $p = p_S/p_A$ denote the relative price of software. As shown in Grossman and Maggi (2000) or similarly argued in Kremer (1993), the output of an industry characterized by supermodular technology is maximized when workers of the same ability work in the same team (firm). Thus, in a competitive equilibrium, where each firm earns no positive profit, the wage structure of the auto industry satisfies

$$(2) \quad w_A(a) = \frac{(na^\alpha)^{\theta/\alpha}}{n} \equiv \lambda a^\theta,$$

³Comparison between our setup and that of Grossman and Maggi (2000) and the reasons for the modifications are provided in Section 5.

⁴The specific production functional form for the auto industry is adopted for illustrative purposes. The same results can be achieved with the following general functional form: $y_A \equiv H(a(1), a(2), \dots, a(n))$ with symmetric tasks such that $\partial^2 H / \partial a(j) \partial a(j') > 0$, for all $j \neq j' \in \{1, 2, \dots, n\}$ and that $H(\kappa a(1), \kappa a(2), \dots, \kappa a(n)) = \kappa^\theta H(a(1), a(2), \dots, a(n))$, with $0 < \kappa$ and $0 < \theta < 1$.

where $\lambda \equiv n^{\frac{\theta}{\alpha}-1}$ corresponds to the benchmark wage when each task is performed by workers of a unit talent. Thus, in each auto firm, the workers sharing the same talent level divide evenly and exhaust the revenue of the auto output. Firms are indifferent between hiring a lower-talent team and a higher-talent team, as the wage payment is reflective of the output response to the talent level. On the other hand, the software industry's wage structure in a competitive equilibrium is simply

$$(3) \quad w_S(a) = pa^\gamma$$

where each software worker receives the whole value of his/her output.

Preferences. Individuals have identical preferences, which are represented by the utility function

$$u(c_{Ai}, c_{Si}) = c_{Ai}^\beta c_{Si}^{1-\beta},$$

where $0 < \beta < 1$, and c_{Ai} and c_{Si} denote individual i 's consumption of cars and software, respectively. The budget constraint is $c_{Ai} + pc_{Si} = w_i$, where w_i is the individual's income that is equal to either $w_A(a_i)$ or $w_S(a_i)$ depending on the worker's occupation. The optimal consumption choices are thus

$$(4) \quad c_{Ai}(p, w_i) = \beta w_i,$$

$$(5) \quad c_{Si}(p, w_i) = \frac{(1-\beta)w_i}{p},$$

which lead to the indirect utility function

$$(6) \quad v(p, w_i) = \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} w_i.$$

Talent Allocation Across Industries. Each worker takes as given the relative price of

software p . A worker joins the auto industry if and only if $w_A(a_i) \geq w_S(a_i)$, which implies

$$(7) \quad a_i \leq \left(\frac{\lambda}{p}\right)^{\frac{1}{\gamma-\theta}} \equiv \tilde{a}(p).$$

As a worker's wage income increases in his own ability at a decreasing rate if he works in the auto industry but at an increasing rate if he works in the software industry, a worker will choose to work in the software industry if his own ability is sufficiently high. In (7), $\tilde{a}(p)$ denotes the highest ability of workers to join the auto industry, which coincides with the ability of the marginal worker who is indifferent between joining either one of the two industries. This cutoff obviously hinges upon the relative goods price.

Lemma 1 $\frac{\partial \tilde{a}}{\partial p} < 0$.

Proof. Based on the definition $\tilde{a}(p)$ in (7), we get $\frac{\partial \tilde{a}}{\partial p} = -\frac{1}{\gamma-\theta} \frac{\tilde{a}}{p} < 0$. ■

The intuition is that, as the relative price of software p falls, a worker's income in the software industry drops; as a result, the cutoff talent level \tilde{a} increases. When the price falls to $p_l \equiv \lambda a_h^{\theta-\gamma}$, even the most talented worker a_h will become indifferent between working in either one of the industries. On the other hand, when the price of software rises above $p_h \equiv \lambda a_l^{\theta-\gamma}$, even the least talented worker a_l will be attracted to work in the software industry. When the cutoff ability is equal to the mean a_m , the corresponding price is $p_m \equiv \lambda a_m^{\theta-\gamma}$, where $p_l \leq p_m \leq p_h$ holds due to $a_h \geq a_m \geq a_l$. For $p \in (p_l, p_h)$, there is incomplete specialization. Our following analyses focus on the scenarios where there is incomplete specialization unless otherwise noted.

Given the talent allocation, the total outputs in the auto and software industry are, respectively,

$$\begin{aligned} Y_A(p, \delta) &= \int_{a_l}^{\tilde{a}} y_A(a) \frac{dF(a)}{n} = \lambda \int_{a_l}^{\tilde{a}} a^\theta dF(a), \\ Y_S(p, \delta) &= \int_{\tilde{a}}^{a_h} a^\gamma dF(a). \end{aligned}$$

Note that an auto firm consists of n workers of the same ability; thus, the density of auto firms is $\frac{1}{n}$ times the density of the auto workers' abilities $dF(a)$ in the above calculation of auto output.

Production Possibility Frontier (PPF). The PPFs corresponding to two different education systems with $\delta_J > \delta_U$ are illustrated in Figure 1. The maximum potential output of software $Y_S^{\max} = \int_{a_l}^{a_h} a^\gamma dF(a)$ is lower with a higher δ , as a higher δ decreases the talent diversity and the software output is convex in talent. On the contrary, the maximum potential output of cars $Y_A^{\max} = \lambda \int_{a_l}^{a_h} a^\theta dF(a)$ is higher with a higher δ , as the auto output is concave in overall talent. Thus, a country with a higher degree of curriculum centralization δ in the education system will have a PPF that is relatively skewed toward the auto output axis and vice versa for a country with a lower level of δ . Note that the corresponding prices at the end points of the PPF are p_l at Y_A^{\max} and p_h at Y_S^{\max} . With a higher δ , p_l increases and p_h decreases; thus, the curvature of PPF also reduces with a higher δ .⁵

Note that for given δ and PPF, an increase in the cutoff ability \tilde{a} corresponds to a migration of workers toward the auto sector from the software sector, which has a positive effect on the auto output and a negative effect on the software:

$$(8) \quad \frac{\partial Y_A}{\partial \tilde{a}} = \lambda \tilde{a}^\theta f(\tilde{a}) > 0,$$

$$(9) \quad \frac{\partial Y_S}{\partial \tilde{a}} = -\tilde{a}^\gamma f(\tilde{a}) < 0.$$

These two conditions imply that $MRT \equiv -\frac{\partial Y_A}{\partial \tilde{a}} / \frac{\partial Y_S}{\partial \tilde{a}} = \lambda \tilde{a}^{\theta-\gamma}$, which is equal to p by (7), verifying the optimality of the competitive equilibrium.

As indicated in Figure 1, for a large range of potential prices, the country with a higher level of δ will produce relatively more auto while the country with a lower level of δ relatively more software, given the same relative price p . Only when the price is extremely high, near the price level at T'_J , will we see a reversal of the positive relationship between the relative auto output and the education policy δ . The following lemma specifies a sufficient condition on the price level for the positive relationship to hold.

Lemma 2 $\frac{\partial Y_A}{\partial \delta} \Big|_p > 0$ and $\frac{\partial Y_S}{\partial \delta} \Big|_p < 0$ for $p \leq p_m$, where $\cdot|_p$ denotes holding p constant.

⁵The range for incomplete specialization (p_l, p_h) is smaller, the higher the education policy δ . In the extreme case when $\delta = 1$, the PPF becomes a straight line (not shown) with a constant slope p_m , and there is incomplete specialization only when the price is exactly equal to p_m .

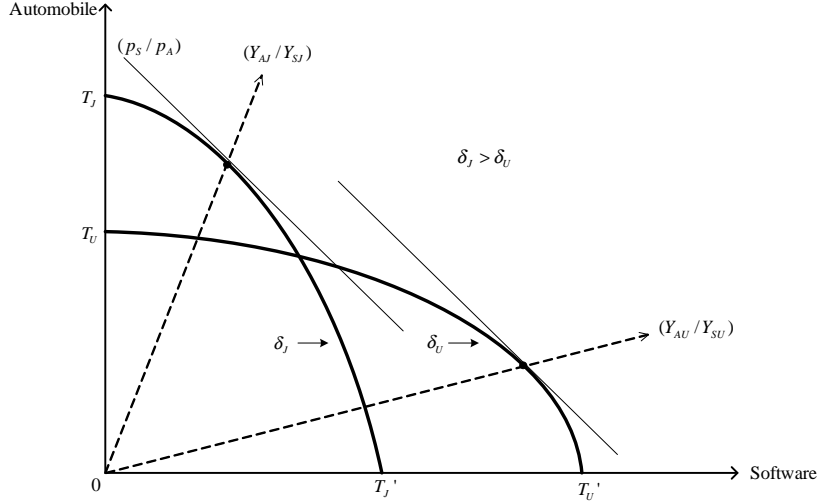


Figure 1: Effects of Education System on PPF

Proof. See the Appendix. ■

Lemma 2 shows that an education system with a higher degree of curriculum centralization δ increases the output of the auto industry but decreases the output of the software industry when the relative price of software is not too high. The intuition is as follows. With the price level (and hence the cutoff talent level \tilde{a}) held constant, an increase in δ reduces the diversity of worker abilities in both industries. Because the auto industry's output is concave in each firm's worker ability while the software industry's output is convex in each worker's ability, a reduced diversity in worker abilities in the above manner has a positive effect on the aggregate auto output and a negative effect on the aggregate software output. Furthermore, an increase in δ also changes the identity ($\tilde{a}_0 = \frac{\tilde{a} - \delta a_m}{1 - \delta}$) of the marginal workers and hence the density of workers in each industry. Within the price range $p \leq p_m$, however, the mean ability workers always work in the auto sector (since $a_m \leq \tilde{a}$), and thus an increase in δ will increase the density of auto workers, reinforcing the first effect. The condition $p \leq p_m$ is sufficient but not necessary for the results in Lemma 2 to hold.⁶

⁶In the price range $p > p_m$ such that the mean ability workers work in the software sector ($\tilde{a} < a_m$), a higher δ will reduce the worker density in the auto sector and raise that in the software sector. This density effect may more than offset the average effect and alter the result. In particular, the reversal is more likely, the further the relative price p increases above p_m and the closer the cutoff level \tilde{a} approaches a_l .

2.3 Equilibrium Analysis

Autarky Equilibrium. In the autarky equilibrium, the domestic markets of both auto and software are clear so that the ratio of total supplies for cars and software is equal to the ratio of their total demands. That is,

$$(10) \quad \frac{\widehat{Y}_A}{\widehat{p}\widehat{Y}_S} = \frac{\int c_A(\widehat{p}, w(a))dF(a)}{\widehat{p} \int c_S(\widehat{p}, w(a))dF(a)} = \frac{\beta}{1 - \beta},$$

where the second equality is derived from (4) and (5), and a decoration \widehat{x} over a variable x indicates the autarky equilibrium value of the corresponding variable x . This leads to the autarky equilibrium price

$$(11) \quad \widehat{p} = \frac{1 - \beta}{\beta} \frac{\widehat{Y}_A}{\widehat{Y}_S},$$

which is unique because the LHS is strictly increasing in p , while the RHS of the equation strictly decreases in p : $\frac{\partial RHS}{\partial p} = \frac{\partial RHS}{\partial \widehat{a}} \frac{\partial \widehat{a}}{\partial p} < 0$ due to $\frac{\partial Y_A}{\partial \widehat{a}} > 0 > \frac{\partial Y_S}{\partial \widehat{a}}$ by (8) and (9), and $\frac{\partial \widehat{a}}{\partial p} < 0$ by Lemma 1.

Lemma 3 *A sufficient condition for $p \leq p_m$ (or equivalently, $a_m \leq \widetilde{a}$) to hold is*

$$(A1) \quad \beta \geq \frac{1}{2} \text{ and } G(a_m) \leq \frac{1}{2}.$$

Proof. See the Appendix. ■

This lemma shows that under condition (A1), the equilibrium price will not be larger than p_m , or equivalently, workers with the mean talent level will work in the auto sector. The same outcome that the mean talent workers work in the supermodular (auto) sector is achieved in Grossman and Maggi (2000) under the assumption of symmetric talent distributions; in comparison, condition (A1) covers more grounds by allowing asymmetric talent distributions as long as the mean talent level is not above the median. The assumption $\beta \geq \frac{1}{2}$ on the preferences implies that a larger proportion of consumption is on manufacturing goods characterized by production chains (e.g., cars, electronics, food, clothing) than on creative products characterized by individual performance

(e.g., software, movies, books, concerts), which seems consistent with reality. In what follows, we assume condition (A1) holds.⁷

Lemma 4 *The autarky equilibrium price increases with the degree of curriculum centralization in the education system, i.e., $\frac{\partial \hat{p}}{\partial \delta} > 0$.*

Proof. Define $V(p, \delta) \equiv (1 - \beta)Y_A(p, \delta) - \beta p Y_S(p, \delta)$. Condition (11) can be rewritten as $V(\hat{p}, \delta) = 0$, based on which we get

$$(12) \quad \frac{\partial \hat{p}}{\partial \delta} = - \frac{\partial V(p, \delta) / \partial \delta}{\partial V(p, \delta) / \partial p} \Big|_{p=\hat{p}} = - \frac{(1 - \beta) \frac{\partial Y_A}{\partial \delta} \Big|_p - \beta p \frac{\partial Y_S}{\partial \delta} \Big|_p}{(1 - \beta) \frac{\partial Y_A}{\partial p} - \beta p \frac{\partial Y_S}{\partial p} - \beta Y_S} \Big|_{p=\hat{p}} > 0$$

since $\frac{\partial Y_A}{\partial \delta} \Big|_p > 0 > \frac{\partial Y_S}{\partial \delta} \Big|_p$ by Lemma 2 and $\frac{\partial Y_S}{\partial p} = \frac{\partial Y_S}{\partial \tilde{a}} \frac{\partial \tilde{a}}{\partial p} > 0 > \frac{\partial Y_A}{\partial \tilde{a}} \frac{\partial \tilde{a}}{\partial p} = \frac{\partial Y_A}{\partial p}$ by (8), (9), and Lemma 1. ■

Lemma 4 shows that the more centralized the education system, the higher the relative autarky price for software in equilibrium. The intuition is obvious; as the relative supply of software is lower when δ is higher and as the preference is homothetic, a closed economy with a higher δ will have a higher relative price for software.

Free Trade Equilibrium. Suppose that a world consists of two representative countries, Japan (J) and the US (U). They have the same economic structure as described above, but different education systems ($\delta_J > \delta_U$). That is, Japan's education system is more centralized than the US's, and as a result, the adult talent distribution a_i is more homogenous in Japan than in the US, though the talent distribution among children (a_{i0}) is identical in the two countries. Rationales for such a difference in education systems across countries even though they are the same in economic structure to begin with will be discussed in Section 3.

Given the different education systems ($\delta_J > \delta_U$), Lemma 4 suggests that Japan will have a higher relative autarky price for software than the US ($\hat{p}_J > \hat{p}_U$). Thus, with the possibility of

⁷Note that condition (A1) is a sufficient but not necessary condition for $p \leq p_m$, which is in turn a sufficient but not necessary condition for Lemma 2. Thus, there is ample room for violations of condition (A1) without invalidating the positive relationship between the relative auto output and the education policy δ .

trade, Japan (the US) will have a comparative advantage in cars (software) and will export cars (software).

By similar arguments as in the case for the autarky price \hat{p} , we know that the free trade equilibrium price \bar{p} is uniquely determined by

$$(13) \quad \bar{p} = \frac{1 - \beta \bar{Y}_{AJ} + \bar{Y}_{AU}}{\beta \bar{Y}_{SJ} + \bar{Y}_{SU}},$$

where Y_{AJ} and Y_{AU} are the auto outputs in Japan and the US, respectively, and Y_{SJ} and Y_{SU} are the software outputs in the two countries. A decoration \bar{x} over a variable x indicates the free trade equilibrium value of the corresponding variable x . It follows that $\hat{p}_J > \bar{p} > \hat{p}_U$ holds for any given education systems in the two countries with $\delta_J > \delta_U$.

The free trade equilibrium price \bar{p} is higher when either δ_J or δ_U is higher, as either change will increase the relative supply of cars in the world market. The following lemma shows this formally.

Lemma 5 *The free trade equilibrium price increases with either country's curriculum centralization in the education system, i.e., $\frac{\partial \bar{p}}{\partial \delta_J} > 0$ and $\frac{\partial \bar{p}}{\partial \delta_U} > 0$.*

Proof. See the Appendix. ■

3 Endogenous Education System

In the previous section, we take education systems as given and analyze its influence on the formation of talent distributions. The predictions on the trade pattern are similar to the existing literature taking talent distributions across countries as given. We now explore the endogenous choice of education systems.⁸

We begin the analysis by characterizing the socially optimal education system under autarky. Given the different choices of education systems under autarky, we then analyze how countries

⁸We have generalized some aspects of the existing models at the cost of restricting other aspects to arrive at a structure that embeds inherent trade-offs in setting education policies. Most existing models do not exhibit such trade-offs; instead, there exists some strictly dominating PPF in these models if PPFs (talent distributions) are allowed to change by policies.

will react to the possibility of trade and how their optimal choice of education system will change compared to autarky.

A higher degree of curriculum centralization in the education system usually corresponds to more rules and regulations imposed on the curriculum, the textbooks, the allocation of school hours, the frequency of tests, and the monitoring of student performance. Requirements such as these entail administrative costs, e.g., to communicate, implement, enforce, and evaluate the rules and regulations. They may also translate into disutility for each student undergoing the system. For example, the disutility could be the lack of flexibility to pursue one's own subjects of interest at different pace or depth, the stress endured during each test, the leisure time sacrificed for study, and so on. The more centralized the education system, the more stringent the rules and regulations, and the more administrative cost and disutility it may entail. For a given degree of curriculum centralization, some country may find it easier to implement than others. For example, if a country is more homogeneous in terms of ethnic composition, the country may find it less costly to set and implement a common set of curriculum and standards, as educators/pupils in the system share similar cultural, linguistic, behavioral or religious traits. In a country where the national/federal government has a stronger administrative capacity relative to the local/state government, the cost of implementing a centralized curriculum may also be lower. To capture these observations, we assume that imposing curriculum centralization entails a disutility of $K_j(\delta) \equiv k_j\delta$ in country j , where $j = J, U$, and $0 < k_J < k_U$. That is, one society attaches a lower disutility to a given level of curriculum centralization than the other society, possibly due to differences in their ethnic compositions or political systems as discussed above. In particular, we assume that the Japanese society find it less costly than the American society in making efforts to conform to homogeneity in education standards (Section 5 provides more discussions on why this seems to be the case).

3.1 Education Systems under Autarky

Given the indirect utility function in (6), the net aggregate welfare of a country implementing a degree of curriculum centralization δ is

$$\begin{aligned}
 U(\delta) &= \int_{a_l}^{a_h} v(p, w(a)) f(a) da - k\delta \\
 &= \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} \int_{a_l}^{a_h} w(a) f(a) da - k\delta \\
 (14) \quad &= \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} (Y_A + pY_S) - k\delta,
 \end{aligned}$$

where we have suppressed the dependence of most variables on the education policy δ to simplify presentations. The last equality holds since the total wage income of the population is equal to the total value of production of the economy by perfect competition. In autarky, the price observes the autarky equilibrium condition (11).

Let δ^a denote the optimal education choice under autarky that maximizes $U(\delta)$ and \hat{p}^a the corresponding autarky equilibrium price. The following first order condition (FOC) must hold at $(\delta, p) = (\delta^a, \hat{p}^a)$:

$$\begin{aligned}
 \frac{\partial U(\delta)}{\partial \delta} &= \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} \left(\left. \frac{\partial Y_A}{\partial \delta} \right|_p + p \left. \frac{\partial Y_S}{\partial \delta} \right|_p + \left(\frac{\partial Y_A}{\partial p} + p \frac{\partial Y_S}{\partial p} \right) \frac{\partial p}{\partial \delta} \right. \\
 &\quad \left. + (\beta Y_S - (1 - \beta) p^{-1} Y_A) \frac{\partial p}{\partial \delta} \right) - k \\
 (15) \quad &= \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} \left(\left. \frac{\partial Y_A}{\partial \delta} \right|_p + p \left. \frac{\partial Y_S}{\partial \delta} \right|_p \right) - k = 0,
 \end{aligned}$$

where the second equality follows, first because $\frac{\partial Y_A}{\partial p} + p \frac{\partial Y_S}{\partial p} = \frac{\partial Y_A}{\partial \tilde{a}} \frac{\partial \tilde{a}}{\partial p} + p \frac{\partial Y_S}{\partial \tilde{a}} \frac{\partial \tilde{a}}{\partial p} = 0$ by the fact that $MRT = -\frac{\partial Y_A}{\partial \tilde{a}} / \frac{\partial Y_S}{\partial \tilde{a}} = p$, and second, by plugging in the autarky equilibrium condition (11). At the optimal choice, the second order condition (SOC) $\left. \frac{\partial^2 U(\delta)}{\partial \delta^2} \right|_{(\delta, p) = (\delta^a, \hat{p}^a)} < 0$ must also hold. Thus, with $k_J < k_U$, it follows that the optimal degree of curriculum centralization under autarky will be higher in Japan than in the US, i.e., $\delta_J^a > \delta_U^a$.

3.2 Education Systems under Trade

Small Open Economy. We first characterize the unilateral optimal choice of education system that would be made by a small open economy. That is, the country takes the world price as given and does not take into account the effect of its choice of education system on the world price. The analysis here thus assumes away the terms-of-trade consideration by a large country when setting the education policy. We will analyze the terms-of-trade effect shortly. As will become clear, many useful insights can be drawn from comparing this simple scenario against the other more comprehensive scenarios.

Proposition 1 *The optimal education system of a small open economy, δ^s , decreases with the given trade price, p .*

Proof. The FOC to maximize the aggregate welfare of a small open economy taking the trade price as given is

$$(16) \quad \frac{\partial U(\delta; p)}{\partial \delta} \Big|_{\delta=\delta^s} = \left[\beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\frac{\partial Y_A}{\partial \delta} \Big|_p + p \frac{\partial Y_S}{\partial \delta} \Big|_p \right) \right]_{\delta=\delta^s} - k = 0.$$

Note that

$$\begin{aligned} \frac{\partial U(\delta; p)}{\partial p} &= \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left[\left(\frac{\partial Y_A}{\partial p} + p \frac{\partial Y_S}{\partial p} \right) - (1-\beta) p^{-1} Y_A + \beta Y_S \right] \\ &= \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} [-(1-\beta) p^{-1} Y_A + \beta Y_S], \end{aligned}$$

where the second equality obtains because $MRT = p$. Based on the above condition, we get

$$\frac{\partial^2 U(\delta; p)}{\partial \delta \partial p} = \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left[-(1-\beta) p^{-1} \frac{\partial Y_A}{\partial \delta} \Big|_p + \beta \frac{\partial Y_S}{\partial \delta} \Big|_p \right] < 0$$

since $\beta < 1$ and $\frac{\partial Y_A}{\partial \delta} \Big|_p > 0 > \frac{\partial Y_S}{\partial \delta} \Big|_p$ by Lemma 2. This implies

$$\frac{\partial \delta^s}{\partial p} = \left[\frac{\partial^2 U(\delta; p)}{\partial \delta \partial p} / \left(-\frac{\partial^2 U(\delta; p)}{\partial \delta^2} \right) \right]_{\delta=\delta^s} < 0,$$

where $\left[\frac{\partial^2 U(\delta; p)}{\partial \delta^2}\right]_{\delta=\delta^s} < 0$ holds by the SOC for δ^s . ■

Proposition 1 states that an increase in the relative price of software, p , will induce a small open economy to adjust downward the the degree of curriculum centralization in its education system, while the opposite is true when p goes down. Note that the autarky optimal education system of country j , δ_j^a , in (15) coincides with its small-open-economy optimal education system in (16) if the given trade price happens to be the same as its autarky price, $p = \widehat{p}_j^a$, where $j = J, U$. That is, $\delta_J^a = \delta_J^s(\widehat{p}_J^a)$ and $\delta_U^a = \delta_U^s(\widehat{p}_U^a)$.

Recall that as countries move from autarky to trade, the free trade price falls relative to the autarky price of the country with an initially more centralized education system and rises relative to the autarky price of the country with an initially more decentralized education system ($\widehat{p}_J^a > \bar{p}^a > \widehat{p}_U^a$), where \bar{p}^a indicates the free trade equilibrium price when δ_J^a and δ_U^a are adopted. Given this, an important implication of Proposition 1 is that as countries move from autarky to trade, a small open economy initially having a more centralized education system will further raise its degree of curriculum centralization (as the relative price of software falls after trade compared to its autarky level) and a small open economy initially having a more decentralized education system will further lower its degree of curriculum centralization (as the relative price of software rises after trade compared to its autarky level).

World Optimal Choice. We now analyze the optimal choice of education systems for the two countries by a world social planner who takes into account the effects of education systems on equilibrium trade volumes and price. The world social planner chooses the education systems that maximize the joint welfare of the two countries:

$$(17) \quad U_w(\delta_J, \delta_U) = \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} (Y_{AJ} + pY_{SJ} + Y_{AU} + pY_{SU}) - k_J \delta_J - k_U \delta_U,$$

where the price observes the free trade equilibrium condition (13). Given (17), we obtain the following FOC for δ_J :

$$\begin{aligned}
\frac{\partial U_w(\delta_J, \delta_U)}{\partial \delta_J} &= \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\left. \frac{\partial Y_{AJ}}{\partial \delta_J} \right|_p + p \left. \frac{\partial Y_{SJ}}{\partial \delta_J} \right|_p \right. \\
&\quad + \frac{\partial Y_{AJ}}{\partial p} \frac{\partial p}{\partial \delta_J} + p \frac{\partial Y_{SJ}}{\partial p} \frac{\partial p}{\partial \delta_J} + Y_{SJ} \frac{\partial p}{\partial \delta_J} \\
&\quad + \frac{\partial Y_{AU}}{\partial p} \frac{\partial p}{\partial \delta_J} + p \frac{\partial Y_{SU}}{\partial p} \frac{\partial p}{\partial \delta_J} + Y_{SU} \frac{\partial p}{\partial \delta_J} \\
&\quad \left. - (1-\beta)p^{-1}(Y_{AJ} + pY_{SJ} + Y_{AU} + pY_{SU}) \frac{\partial p}{\partial \delta_J} \right) - k_J \\
(18) \qquad \qquad \qquad &= \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\left. \frac{\partial Y_{AJ}}{\partial \delta_J} \right|_p + p \left. \frac{\partial Y_{SJ}}{\partial \delta_J} \right|_p \right) - k_J = 0,
\end{aligned}$$

where the second equality follows by the fact that $MRT = p$ in both countries and by plugging in the free trade equilibrium condition (13). Similarly, we can obtain the following FOC for δ_U :

$$(19) \qquad \frac{\partial U_w(\delta_J, \delta_U)}{\partial \delta_U} = \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\left. \frac{\partial Y_{AU}}{\partial \delta_U} \right|_p + p \left. \frac{\partial Y_{SU}}{\partial \delta_U} \right|_p \right) - k_U = 0.$$

Let $\delta_J^w(\delta_U)$ denote the solution of δ_J to (18) given any δ_U , and similarly let $\delta_U^w(\delta_J)$ denote the solution of δ_U to (19) given any δ_J . It is straightforward to verify that $\frac{\partial^2 U_w(\delta_J, \delta_U)}{\partial \delta_J \partial \delta_U} < 0$; thus, it follows that $\frac{\partial \delta_J^w(\delta_U)}{\partial \delta_U} < 0$ and $\frac{\partial \delta_U^w(\delta_J)}{\partial \delta_J} < 0$. These two FOC's are illustrated in Figure 2. The optimal choice of education systems by the world social planner, δ_J^w and δ_U^w , for Japan and the US, corresponds to the intersection W of the two schedules $\delta_J^w(\delta_U)$ and $\delta_U^w(\delta_J)$. The fact that $k_J < k_U$ is reflected by the fact that the schedule $\delta_J^w(\delta_U)$ is further away from the origin than the schedule $\delta_U^w(\delta_J)$, and as a result, the optimal degree of curriculum centralization for Japan, δ_J^w , is higher than that for the US, δ_U^w . Let \bar{p}^w indicate the free trade equilibrium price when (δ_J^w, δ_U^w) are adopted.

Note that these two FOC's, (18) and (19), coincide with the FOC (16) for small open economies taking the trade price as given. The intuition for this result is that the terms-of-trade considerations in setting δ when countries perceive their market powers are neutralized in a world social planner's problem since one country's terms-of-trade gain is the other country's terms-of-trade loss. This

can be seen in the derivations of (18), where the effects of δ_J on p and the effects of p on the joint income and welfare of the two countries are eliminated in the final expression. The only things that matter are the direct effect of δ_J on Japan's own production choice and that of δ_U on the US's own production choice. Thus, the optimal choice of education systems by a world social planner turns out to be the same as the noncooperative equilibrium choice of education systems by individual countries if they behave as price takers.

Proposition 2 *The optimal choice of education systems (δ_J^w, δ_U^w) by a world social planner that maximizes the world welfare under trade coincides with the noncooperative equilibrium choice of education systems by individual countries behaving as price takers in the world market. Relative to autarky, the difference in education styles is further enlarged after trade in the world socially optimal outcome: $\delta_J^w > \delta_J^a > \delta_U^a > \delta_U^w$.*

Proof. If Japan behaves as a price taker, its FOC to maximize its aggregate welfare is (16) with $k = k_J$, which is identical to the world social planner's FOC (18). Thus, $\delta_J^w(\delta_U)$ can also be regarded as Japan's best response function, when Japan behaves as a price taker, where the price taken as given by Japan follows the trade equilibrium condition (13) for given δ_U and δ_J . Similarly, $\delta_U^w(\delta_J)$ can also be regarded as the US's best response function, when the US behaves as a price taker. The noncooperative equilibrium outcome, when each of these two countries maximizes their individual welfare but behaves as price takers, occurs at the intersection W of the two schedules $\delta_J^w(\delta_U)$ and $\delta_U^w(\delta_J)$, which is identical to the world social planner's choice. This proves the first part of the proposition.

To show the second part of the proposition, note that if k_U were to decrease to the level of k_J , $\delta_U^w(\delta_J)$ would shift out (not shown) in Figure 2 and intersect $\delta_J^w(\delta_U)$ at point W_J on the 45° line. This is the hypothetical world social planner's choice if both countries had identical disutility factors equal to k_J . But if both countries were identical, the equilibrium trade price would be equal to either country's autarky price. In particular, this is Japan's realized autarky price with k_J . Hence, the level of δ_J corresponding to point W_J is Japan's autarky optimal choice of education system, given that the FOC for Japan's autarky decision (15) and the FOC for the world social

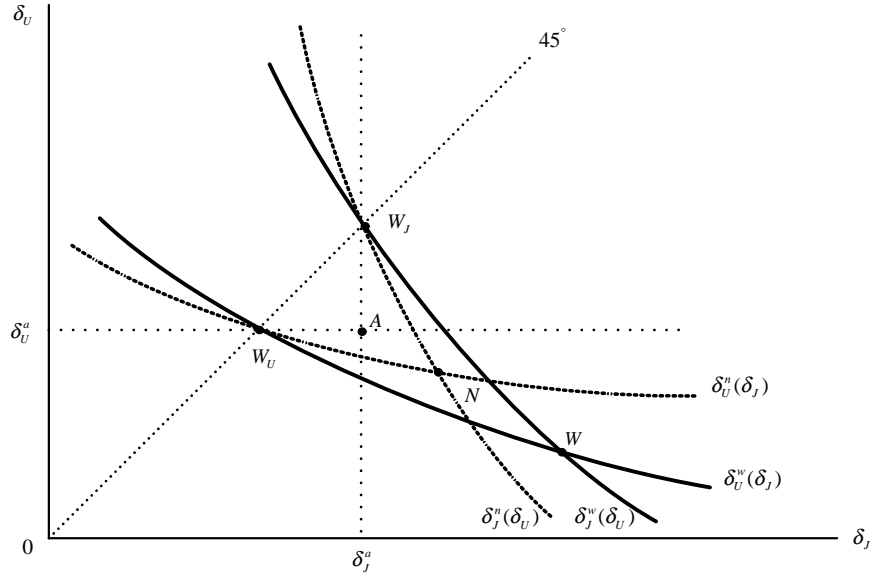


Figure 2: Endogenous Choice of Education System

planner's decision of Japan's education system (18) are identical if evaluated at the same price level.

Analogously, if k_J were to increase to the level of k_U , $\delta_J^w(\delta_U)$ would shift in (not shown) and intersect $\delta_U^w(\delta_J)$ at point W_U on the 45° line in Figure 2. This is the hypothetical world social planner's choice if both countries had identical disutility factors equal to k_U . But then the equilibrium trade price would be equal to either country's autarky price. In particular, this is the US's realized autarky price with k_U . Hence, the level of δ_U corresponding to point W_U is the US's autarky optimal choice of education system, given that the FOC for the US's autarky decision (15) and the FOC for the world social planner's decision of the US's education system (19) are identical if evaluated at the same price.

Thus, the combination of the socially optimal education systems under autarky in the two countries corresponds to point A in Figure 2. It lies to the northwest of the world social planner's choice with trade W . The result $\delta_J^w > \delta_J^a > \delta_U^a > \delta_U^w$ therefore follows. ■

Thus, from the world's perspective, it is socially optimal to further enlarge the autarky difference in the education systems between Japan and the US to reinforce their initial pattern of comparative

advantage and to maximize the gains from trade. With endogenous education policies (and PPFs), the output response to the possibility of trade is more elastic and the potential gains from trade are bigger than classical trade theories with given PPFs would suggest. Not only does the world aggregate production increase as individual countries reallocate more productive resources to their sector of comparative advantage (corresponding to a movement along the given PPF), but it is further enlarged as individual countries revise their education policies (and restructure their PPFs) to be further skewed toward their sector of comparative advantage.

Nash Equilibrium Choice. If countries choose education systems unilaterally (as is likely the case in reality) and take into consideration the terms-of-trade effect of their education policies, the resulting Nash equilibrium $(\delta_J^n, \delta_U^n, \bar{p}^n)$ tends to differ from the above socially optimal outcome $(\delta_J^w, \delta_U^w, \bar{p}^w)$. The intuition is that Japan would not want to raise δ_J in the Nash equilibrium as much as it would as a price taker (or in the world optimal outcome), since a higher δ_J increases the auto output, depresses the world price of cars which it exports, and hurts its terms of trade; the reverse is true for the US, who would not want to lower δ_U in the Nash equilibrium as much as it would as a price taker. Such a terms-of-trade loss is ignored by a small open economy, or is offset by the equivalent terms-of-trade gain of the other country in a world social planner's calculation. Thus, by taking the terms-of-trade effect into consideration, countries tend to specialize less than in the socially optimal outcome. This is formally proved in the following proposition.

Proposition 3 *In a free trade equilibrium where each country simultaneously chooses its education system taking as given the other country's choice, the education systems in Japan and the US diverge more from their autarky levels but less than the socially optimal levels: $\delta_J^w > \delta_J^n > \delta_J^a > \delta_U^a > \delta_U^n > \delta_U^w$.*

Proof. The objective function of Japan is

$$(20) \quad \max_{\delta_J} U_J(\delta_J; \delta_U) = \beta^\beta (1 - \beta)^{1-\beta} p^{-(1-\beta)} (Y_{AJ} + pY_{SJ}) - k_J \delta_J$$

subject to the trade equilibrium condition (13). The FOC for a best response $\delta_J^n(\delta_U)$ given δ_U is

$$\begin{aligned}
\frac{\partial U_J(\delta_J; \delta_U)}{\partial \delta_J} &= \left[\beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\frac{\partial Y_{AJ}}{\partial \delta_J} \Big|_p + p \frac{\partial Y_{SJ}}{\partial \delta_J} \Big|_p \right. \right. \\
&\quad \left. \left. + \frac{\partial Y_{AJ}}{\partial p} \frac{\partial p}{\partial \delta_J} + p \frac{\partial Y_{SJ}}{\partial p} \frac{\partial p}{\partial \delta_J} + Y_{SJ} \frac{\partial p}{\partial \delta_J} \right. \right. \\
&\quad \left. \left. - (1-\beta)p^{-1}(Y_{AJ} + pY_{SJ}) \frac{\partial p}{\partial \delta_J} \right) \right] - k_J \\
&= \left[\beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\frac{\partial Y_{AJ}}{\partial \delta_J} \Big|_p + p \frac{\partial Y_{SJ}}{\partial \delta_J} \Big|_p \right. \right. \\
(21) \quad &\left. \left. + \beta \frac{Y_{SJ}Y_{AU} - Y_{SU}Y_{AJ}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_J} \right) \right] - k_J = 0.
\end{aligned}$$

The second equality follows again by the fact that $MRT = p$ and by plugging in the trade equilibrium condition (13). Given that $\frac{\partial p}{\partial \delta_J} > 0$ by Lemma 5, it follows that $\frac{Y_{SJ}Y_{AU} - Y_{SU}Y_{AJ}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_J} \leq 0$ if and only if $\delta_J \geq \delta_U$. Comparing the FOC for $\delta_J^n(\delta_U)$ in (21) with the FOC for $\delta_J^w(\delta_U)$ in (18) implies that $\delta_J^n(\delta_U) \leq \delta_J^w(\delta_U)$ if and only if $\delta_J \geq \delta_U$. The position of $\delta_J^n(\delta_U)$ relative to $\delta_J^w(\delta_U)$ is illustrated in Figure 2. For example, in the area below the 45° line we have $\delta_J > \delta_U$, which implies $Y_{AJ} > Y_{AU}$ and $Y_{SU} > Y_{SJ}$ so that the term $\frac{Y_{SJ}Y_{AU} - Y_{SU}Y_{AJ}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_J}$ is negative; this in turn suggests that the best response function $\delta_J^n(\delta_U)$ lies to the left of $\delta_J^w(\delta_U)$ of the world social planner. In addition, the divergence between the two is larger, the more asymmetric the two countries are in their education systems and hence in their production patterns (reflected as a larger term $\frac{Y_{SJ}Y_{AU} - Y_{SU}Y_{AJ}}{Y_{AJ} + Y_{AU}}$ in absolute value). The opposite is true for the area above the 45° line, where $\delta_J < \delta_U$ and thus $\delta_J^n(\delta_U)$ lies to the right of $\delta_J^w(\delta_U)$. Finally, the two lines $\delta_J^n(\delta_U)$ and $\delta_J^w(\delta_U)$ cross each other on the 45° line when $\delta_J = \delta_U$, as in this case, the two countries have the same production structures and the term $\frac{Y_{SJ}Y_{AU} - Y_{SU}Y_{AJ}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_J}$ is equal to zero.

The objective function of the US is

$$(22) \quad \max_{\delta_U} U_U(\delta_U; \delta_J) = \beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} (Y_{AU} + pY_{SU}) - k_U \delta_U$$

subject to the trade equilibrium condition (13). The FOC for a best response $\delta_U^n(\delta_J)$ given δ_J can be obtained analogously:

$$(23) \quad \frac{\partial U_U(\delta_U; \delta_J)}{\partial \delta_U} = \left[\beta^\beta (1-\beta)^{1-\beta} p^{-(1-\beta)} \left(\frac{\partial Y_{AU}}{\partial \delta_U} \Big|_p + p \frac{\partial Y_{SU}}{\partial \delta_U} \Big|_p + \beta \frac{Y_{SU}Y_{AJ} - Y_{SJ}Y_{AU}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_U} \right) \right] - k_U = 0.$$

By the same token, the term $\frac{Y_{SU}Y_{AJ} - Y_{SJ}Y_{AU}}{Y_{AJ} + Y_{AU}} \frac{\partial p}{\partial \delta_U} \gtrless 0$ if and only if $\delta_J \gtrless \delta_U$. Comparing the FOC for $\delta_U^n(\delta_J)$ in (23) with the FOC for $\delta_U^w(\delta_J)$ in (19) implies that $\delta_U^n(\delta_J) \gtrless \delta_U^w(\delta_J)$ if and only if $\delta_J \gtrless \delta_U$; similarly, the divergence between the two is larger, the more asymmetric the two countries are in their education systems, and as a result, in their production patterns. The position of $\delta_U^n(\delta_J)$ relative to $\delta_U^w(\delta_J)$ is illustrated in Figure 2.

The Nash equilibrium $(\delta_J^n, \delta_U^n, \bar{p}^n)$ is determined jointly by the two FOC's (21) and (23). It occurs at the intersection N of the two schedules $\delta_J^n(\delta_U)$ and $\delta_U^n(\delta_J)$ in Figure 2 and lies to the northwest of the world social planner's choice W but to the southeast of the autarky choice A ; thus, it follows that $\delta_J^w > \delta_J^n > \delta_J^a > \delta_U^a > \delta_U^n > \delta_U^w$. ■

Note that in either the individual autarky optimization problem or the world social planner's optimization problem, the effect of the endogenous price change on the autarky welfare or the joint world welfare is zero. A software price increase has a positive income effect scaled by the output of the software industry. At the same time, it entails a negative consumption effect. In autarky, the two effects offset each other, as production equals consumption. In the joint welfare calculation, the two effects similarly offset each other, as the two countries' joint production equals their joint consumption.

This is not the case when countries optimize individual welfare under trade. For an auto-exporting country, it produces relatively less software than it consumes; thus, a software price increase will lead to relatively less income gain than consumption loss, and as a result, an overall terms-of-trade loss. The opposite is true for the software-exporting country. Hence, whenever $\delta_J > \delta_U$ and as a result, Japan is an exporter of cars, Japan would not want to raise its degree of curriculum centralization as high as the world social planner's optimal choice, because a higher

degree of curriculum centralization increases the auto output, increases the relative price of software which it imports, and creates a terms-of-trade loss. In contrast, the US, as an exporter of software, would not want to lower its degree of curriculum centralization as low as the world social planner's optimal choice, because a lower degree of curriculum centralization increases the software output, decreases its relative price, and creates a terms-of-trade loss. Thus, as shown in Figure 2, $\delta_J^n(\delta_U)$ lies to the left of $\delta_J^w(\delta_U)$ while $\delta_U^n(\delta_J)$ lies above $\delta_U^w(\delta_J)$ in the area to the right of the 45° line where $\delta_J > \delta_U$.

The more asymmetric the two countries are in their education systems and hence the more imbalanced they are in their production structures, the stronger the terms-of-trade effect. This is reflected in Figure 2 by the larger distance between $\delta_J^n(\delta_U)$ and $\delta_J^w(\delta_U)$ or that between $\delta_U^n(\delta_J)$ and $\delta_U^w(\delta_J)$ as one moves further away from the 45° line. As indicated by Figure 2, the two countries' education systems at the Nash equilibrium (point N) are more divergent than in autarky (point A), but are not as divergent as would be prescribed by the world social planner's optimal choice (point W).

4 Empirical Relevance

In this section, we present some measures of curriculum centralization in education systems and its effects on talent diversity. We also provide some preliminary empirical evidence on the effects of trade intensity change on cross-country differences in education systems.

The measures are constructed based on data from the Trends in International Mathematics and Science Study (TIMSS), an international assessment of math and science knowledge of the fourth-grade and eighth-grade students around the world. Our curriculum centralization and student performance measures are based on grade 8 results, which presumably exhibit a larger influence of education systems than those of grade 4 (Hanushek and Kimko 2000). TIMSS was first administered in 1995 and every four years thereafter (1999, 2003, and 2007). Participating countries, however, vary across years. Since talent diversity in reality may be affected by many factors in addition to curriculum, such as the initial talent pool, access to public education and investment in education,

we focus on the sample of participating OECD countries, which are relatively homogeneous in these other relevant controls.⁹

Score Diversity Measure. Following the literature, we measure a country’s talent diversity by the standard deviations of the math/science scores divided by their means. Specifically, it is measured by $(\frac{\sigma_m}{\mu_m} + \frac{\sigma_s}{\mu_s})/2$, where σ_m and μ_m are, respectively, the standard deviation and the mean of the math scores for the eighth-grade students, while σ_s and μ_s are those for science scores.¹⁰

Curriculum Centralization Measure. Given the data in TIMSS, there are two plausible ways to measure curriculum centralization in a country. The first measure is based on the responses of the national representative to the *curriculum questionnaire* which asks whether any of the seven listed methods are “used to help implement the national mathematics (science) curriculum at grade 8”. The measure is the sum of yes (=1) or no (=0) answers to the seven questions if there exists such a national curriculum, and it is zero if no national curriculum exists in a country.¹¹ Since the answers are often the same for both math and science curricula in the sample of OECD countries, the final measure is the average of the two, and its scale is normalized to the unit interval. A larger measure indicates a higher degree of curriculum centralization at the national level. This measure is available only in the 2003 survey.

Countries with similar stated centralization policies at the national level, however, may differ from each other in their actual implementation practices at the school level; the differences may also evolve over time even when the written policy does not change (Astiz et al. 2002). In view of this, our second measure of curriculum centralization incorporates information of school-level practices, where we take the average of the national-level measure constructed above and the school-level implementation index discussed below.

⁹Appendix B gives the list of participating OECD countries. In particular, we will restrict our attention to the OECD countries which were current members by 2003 (when the last TIMSS survey used in our study was conducted), and where all regions in a country participated in TIMSS together.

¹⁰These statistics can be found in TIMSS 1995 Mathematics (Science) Achievement in the Middle School Years Table E.3, TIMSS 1999 International Mathematics (Science) Report Exhibit D.2, and TIMSS 2003 International Mathematics (Science) Report Exhibit D.2.

¹¹See Q.1A and Q.3 in TIMSS 2003 Curriculum Questionnaire for Mathematics, and Q.1A and Q.4 in TIMSS 2003 Curriculum Questionnaire for Science. The seven listed methods are: a) mandated or recommended textbook(s), b) instructional or pedagogical guide, c) ministry notes and directives, d) curriculum evaluation during or after implementation, e) specifically developed or recommended instructional activities, f) national assessments based on student samples, g) a system of school inspection or audit. The data are found in the files, BUGMATM3.xls and BUGSCIM3.xls, from TIMSS 2003.

In TIMSS 1995 and 1999, the *school questionnaire* addressed to school principals includes 15 questions regarding the importance of various forces in determining the curriculum. These 15 forces can be regarded to represent centralizing or decentralizing forces in view of our model. For instance, the first question asks “How much influence does the National Curriculum Council have in determining curriculum?” where 1=none, 2=a little, 3=some and 4=a lot. In light of our theory, this factor represents a centralizing force as it tends to impose homogeneity on the curriculum structures across schools. So are two other factors, National Subject Association and external examinations/standardized tests, asked in two other questions. In contrast, the remaining 12 factors in the list refer to local or school forces which tend to introduce heterogeneity in curricula across schools.¹² The importance of each variable (ranging from 1 to 4) is the average response of all valid samples in a country. If a variable was coded as N.A. for all cases in a country, we treat it as having no influence in the country and assign the variable a value of 1, since the most likely reason for this case is that the question was not applicable to the country’s context. For example, the US does not have a national curriculum council and the question was not administered in 1995.¹³ The school-level implementation index is calculated as the ratio of the average importance of the three centralizing forces and the average importance of the 12 decentralizing forces; it is then normalized to the unit interval to be consistent with the national-level measure.¹⁴

The national-level measure has good international comparability, as the curriculum questionnaire is answered by a national representative, and the relevant questions we use in constructing the measure are the same across countries. In contrast, some questions used in the school-level index could be deleted or modified by countries in accordance with their national education systems. The adaptations could also differ across waves of surveys in the same country. As a result, the

¹²See items SCQ2-13A to SCQ2-13O in TIMSS 1995 Population 2 School Questionnaire, and items SCQ2-9A to SCQ2-9O in TIMSS 1999 School Questionnaire. The questions refer to the influence of: A) National Curriculum Council, B) National Subject Association, C) Educational region or district, D) School governing board, E) Principal/head of school, F) Teachers (collectively for the school), G) Teachers (of same subject) as a group, H) Each teacher individually, I) Parents, J) Students, K) Church/religious groups, L) Business community, M) Textbook publishers, N) External examinations/standardized tests, O) Teacher unions. The options in A)–D) may be modified in accordance with national education systems. The data are found in the files, BSALM92M1.TXT or BSALM42M1.TXT from TIMSS 1995, and bsalm3_m2.pdf or bsalm4_m2.pdf from TIMSS 1999.

¹³See TIMSS 1995 User Guide for the Primary and Middle School Years (Chapter 7-30) for more discussions of N.A. entries.

¹⁴This school-level index is highly correlated with the 1995 operational centralization measure in Astiz et al. (2002).

cross-country comparability of the school-level index by itself is noisy.¹⁵ Thus, the average of the national-level measure and the school-level implementation index aims to capture the international comparability of the national-level measure and at the same time to incorporate the time-series variation in the tendency of curriculum centralization observed at the school level. Because the national-level measure is only observed in 2003 while the school-level index is only observed in 1995 and 1999, the centralization measure for 1995 is constructed as the average of the 1995 school-level index and the 2003 national-level measure. The centralization measure for 1999 is constructed similarly.¹⁶

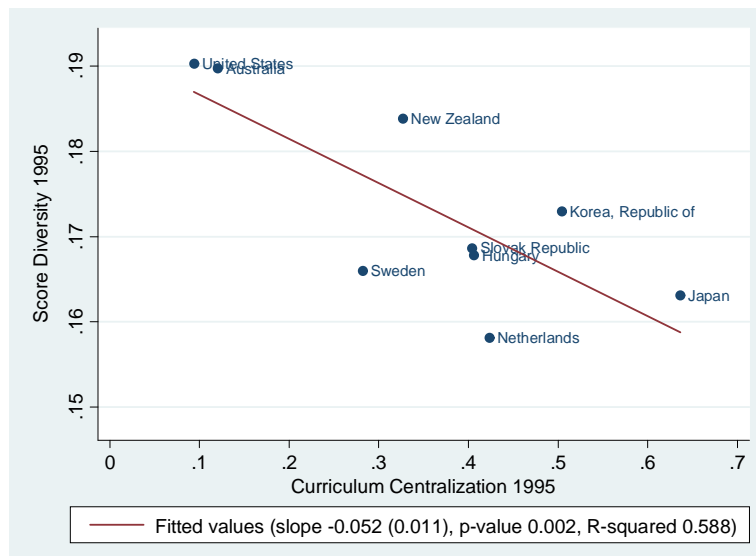


Figure 3: Curriculum Centralization and Score Diversity 1995

Curriculum Centralization and Score Diversity. When we regress the score diversity on the degree of curriculum centralization in the sample of OECD countries, a negative and statistically significant relationship emerges in all three years of surveys.¹⁷ Figure 3 presents the regression

¹⁵For example, the US did not administer the question of National Curriculum Council in 1995, but replaced the option by Voluntary National Standards in 1999. In this case, we recoded the 1999 score for the variable to 1 as in 1995, judging that the substitute option does not constitute official standards with enforcement power. In other cases, it is less than clear whether and how any adjustment should be made. See TIMSS 1995 User Guide for the Primary and Middle School Years Supplement 3 (Section 7-8), and TIMSS 1999 User Guide Supplement 2 (Section 4-6 to 4-8) for the complete list of national adaptations of the school questionnaire.

¹⁶Ideally, the national-level measure and the school-level index of the same year should be used in the average, but data for the 1995/1999 national-level measure are absent. It is reckoned that the national-level measure reflects the slow-moving component of education policies and likely does not change much in the short run.

¹⁷Robust standard errors are used in the estimation.

result for year 1995, where the estimated slope coefficient is negative and highly significant.¹⁸ The same result also holds for year 1999; as shown in Figure 4, the estimated slope is quite similar to that in 1995 even though the samples are slightly different. Figure 5 suggests that the negative and significant relationship between curriculum centralization and score diversity also holds in 2003 when the national-level measure of curriculum centralization is used. These results suggest that the more centralized a country’s curriculum structure is, the more homogeneous its student performance tends to be, which is consistent with our theoretical characterization of the education system and its effect on talent distribution.¹⁹ Incidentally, the data also show clearly that the US and Japan indeed have the most extreme education systems in terms of curriculum centralization in the sample of countries.

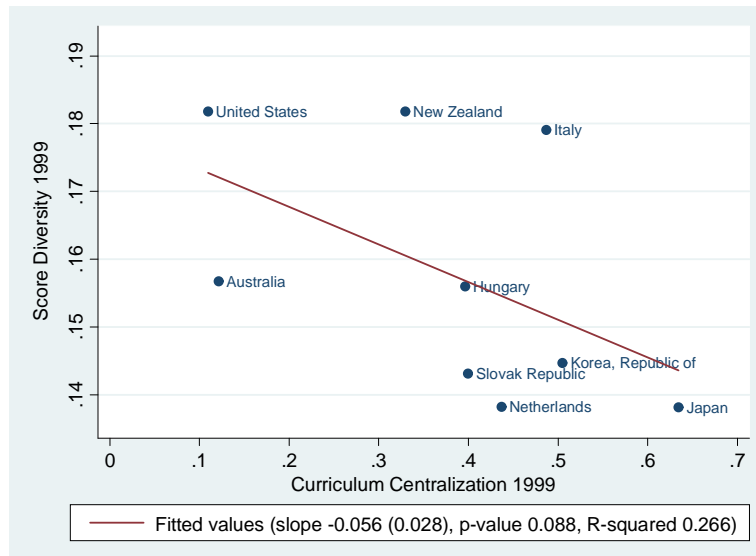


Figure 4: Curriculum Centralization and Score Diversity 1999

Education System and Trade. Our theory predicts a wider divergence in education policies between countries as they go from no trade to completely free trade. In reality, we do not observe the autarky state but the rise and fall in trade intensity between countries. Thus, we look instead

¹⁸ Among the 11 OECD countries who participated in both TIMSS 1995 and 2003 (so that the 1995 curriculum centralization measure can be constructed), Italy does not have the 1995 score and school survey data, and Norway does not have the 1995 centralization measure data.

¹⁹ The results are very similar if we regress the score diversity on curriculum centralization with a four-year lag (e.g., the score diversity of 1999 on the curriculum centralization in 1995) or with a eight-year lag.

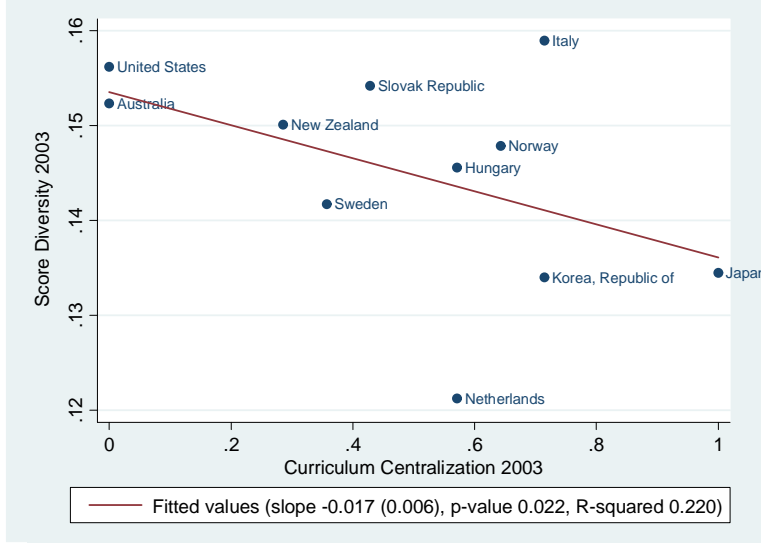


Figure 5: Curriculum Centralization and Score Diversity 2003

at the relationship between the change in bilateral trade intensity over time for a pair of countries and the corresponding change in their education styles to see whether the empirical pattern is consistent with our prediction.

A second caveat is that our theoretical prediction is more of a long-run relationship, but measures of curriculum centralization comparable across countries over a long period of time are not available. What we have are the second measures of curriculum centralization for both 1995 and 1999. In this time frame, they likely reflect more of short-run variations in the school-level implementation than long-run shifts in the national-level policy. They are also relatively noisy for reasons mentioned above. Given this, it is likely difficult to detect a systematic relationship between education and trade based on this dataset. Therefore, in the end, the empirical evidence we can show is extremely preliminary.

The change in relative difference in education systems between a pair of countries (k, l) is measured by $|central_{k,99} - central_{l,99}| - |central_{k,95} - central_{l,95}|$, where $central_{c,t}$ is the curriculum centralization measure for country c in year t .²⁰ The larger the measure, the more divergent the

²⁰To accommodate a swap in the relative ranking of centralization between a pair of countries, a more general measure $sign(central_{k,99} - central_{l,99}) * [(central_{k,99} - central_{l,99}) - (central_{k,95} - central_{l,95})]$, should be used. When such swaps do not occur, which is the case for the sample used in the trade regression, it is equivalent to the measure shown in the text.

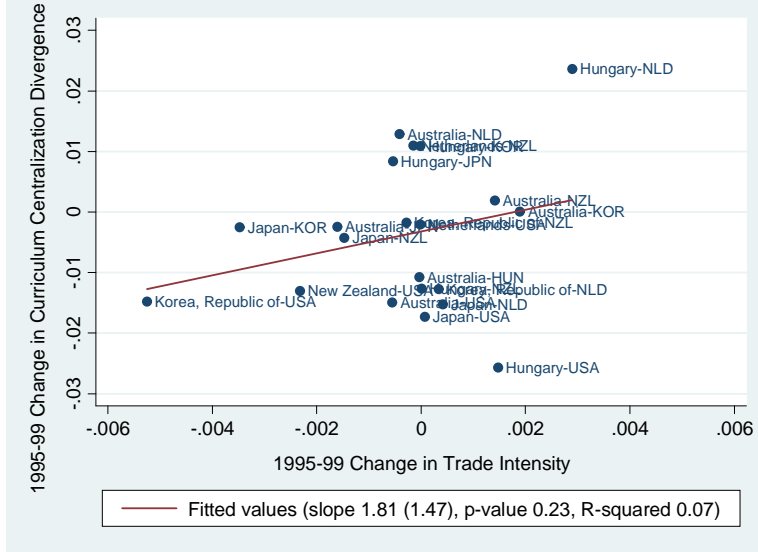


Figure 6: Education System Difference and Trade Intensity

two countries' education policies have become from 1995 to 1999.

The trade intensity between a pair of countries (k, l) in a year is measured by the average of their bilateral export intensity $(\frac{export(k,l)}{GDP(k)} + \frac{export(l,k)}{GDP(l)})/2$, where $export(k, l)$ indicates the amount of exports from country k to country l . We take a five-year moving average; for example, the trade intensity measure for 1995 is the average over the years from 1990 to 1994. This moving-average trade measure accommodates possible time lag of trade pattern in influencing education policies; it also helps smooth out short-run fluctuations in the trade flows.²¹ For this analysis, the sample of OECD countries is further reduced to those with both 1995 and 1999 curriculum centralization measures and for which the bilateral trade data are available in both years.²²

Figure 6 presents the result of regressing the change of relative difference in curriculum centralization between a pair of countries on the change in their bilateral trade intensity between 1995 and 1999. The estimated slope coefficient is positive and the fitted line passes through $(0, 0)$ approximately. Thus, pairs of OECD countries that become more intensive in their bilateral trade

²¹The bilateral trade data (denominated in the US currency) are taken from the IMF Direction of Trade Statistics database in July 2010. The GDP data in the US currency are constructed from the GDP data in local currencies and the exchange rate series from the IMF International Financial Statistics database (accessed in August 2010). The period-average exchange rate series are used.

²²Among the eight common countries in Figures 3 and 4, Slovak Republic does not have the 1995 trade intensity data with the other countries.

from 1995 to 1999 tend to become more divergent from each other in their degrees of curriculum centralization, and vice versa. This is consistent with our theoretical prediction. Given the caveats noted above, the result is quite encouraging, although the estimation is not statistically significant at the conventional level. That said, it is clear that having comparable measures of curriculum centralization at extended periods of time is necessary to provide more persuasive findings. We leave this for future work.

5 Discussions

Modeling Choices. Grossman and Maggi (2000) introduce a stylized framework to analyze the effects of talent distribution on trade pattern, taking the underlying talent distribution as given. In particular, the framework emphasizes the coexistence of a supermodular sector (say, auto) and a submodular sector (say, software) with the production technology of both sectors consisting of two tasks and exhibiting constant returns to talent used in the two tasks. The supermodular (submodular) production technology is characterized by input complementarity (substitutability) and thus encourages self-matching (cross-matching) in the abilities of workers constituting a production team. With constant returns to overall talent, the supermodular (submodular) production technology also implies a decreasing (increasing) return to individual talent in a production team.

It may be useful to explain why we are not adopting their exact production technology specifications, and to what extent our alternative specifications have preserved or deviated from the characteristics of their framework. First, given constant returns to overall talent in their framework, a country's maximum output in the supermodular sector depends only on the country's mean talent level, while its maximum output in the submodular sector increases with the country's talent diversity. With an endogenous education policy as introduced above, an increase in δ does not alter the mean ability and the maximum output of the supermodular good, but decreases the talent diversity and the maximum output of the submodular good. Thus there would be no trade-off in setting δ , and a lower δ strictly dominates a higher one, defeating any purpose to rationalize different choices of δ across countries. Thus, we preserve the supermodularity but impose decreasing returns to

overall talent in the auto sector, so that an increase in δ increases the maximum output of the supermodular good. We generalize their original 2-task framework to n -tasks for the supermodular sector, which is a straightforward generalization and agrees with the image of a long production chain typical of such production processes.

Second, given the modifications to the supermodular sector, the effects of goods price change on the wage structure of the software worker and hence the talent allocation across the two sectors cannot be signed, which hinders attempts of comparative statics analysis. Thus, we simplify the submodular production technology in the software sector to consist of only a single task instead of two; actually, with a submodular production technology, it increases the aggregate output to break up a production team of any size and conduct the work individually, which was also pointed out by Grossman and Maggi (2000). The increasing return to individual talent in a submodular production process is preserved by assuming an increasing return to the talent used in the single task. Given the alternative technology specifications, the convexity of the software industry's wage structure is preserved, while the auto industry's wage structure becomes concave instead of being linear, reflecting the decreasing returns to overall talent. Instead of two cutoffs in the talent allocation reflecting cross-matching of the lowest and the highest abilities of workers in the software industry in Grossman and Maggi (2000), there is only one cutoff in the talent allocation in our framework: the less-talented workers self-match to toil in the auto sector and only the more-talented workers choose to work alone in the software sector. Thus, our framework does not imply a necessarily higher talent (wage) dispersion in the submodular sector as would arise in the framework of Grossman and Maggi (2000).

The main results of this paper on the pattern of endogenous education systems following trade are robust to many variations to the current technology specifications. In fact, any such specifications that lead to the comparative static results $(\frac{\partial Y_A}{\partial \delta} \Big|_p > 0 > \frac{\partial Y_S}{\partial \delta} \Big|_p)$ in Lemma 2 will suffice. In other words, as long as the output of one industry increases in the homogeneity of abilities while that of the other industry decreases in it, our main results will go through. More generally, our analytical framework and results can be applied to other dimensions of education systems as long as they affect different industries in distinct ways.

In the model, we have taken country sizes to be the same across countries (with a unit measure of population). As the production technologies in both sectors exhibit constant returns to *scale* (the measure of population, say, L) and the preferences are identical and homothetic in the two countries, the country sizes can differ without affecting the comparative advantage and trade pattern. It is also straightforward to verify that introduction of different country sizes (L_J, L_U) will not affect the qualitative results regarding the endogenous choice of education systems.

In the main text, we have used a linear disutility function to capture the cost for a country to implement a certain degree of curriculum centralization. A more general functional form can be adopted without changing our substantial results. For example, an alternative disutility functional form could be $K(\delta, k)$, where the disutility increases with the level of curriculum centralization δ and a parameter k , with $\frac{\partial K(\delta, k)}{\partial \delta \partial k} > 0$ such that the marginal disutility with respect to δ is higher when k is larger.

Education and Skills. The education system in the model is characterized by a single parameter δ that measures the level of curriculum centralization imposed on educators/students, where a more centralized education system decreases the skill gaps among students but by its very nature also reduces the diversity in talent. Available evidence suggests that this captures the crucial difference between the Japanese and the US education systems. The US students, for example, exhibit larger diversity in international test scores in math and science than the Japanese students as we have seen in the empirical section, and the more so among the secondary-school students than the elementary-school students (Hanushek and Kimko 2000, Hanushek 2002). Some scholars argue that initiative, creativity, and entrepreneurship are emphasized more in the US education, which are difficult to measure by standardized tests (Mayer, Tajika, and Stanley 1991, Bracey 2002, Ramirez et al. 2006). While we acknowledge that it is possible to increase the basic skill level in some dimensions (e.g., reading, math and science) for all students without reducing the desirable diversity in other dimensions, our key insight on the fundamental trade-off among different sets of skills remains valid, since resources that can be devoted to all these dimensions of skills cannot be unlimited and thus some tough allocation decisions have to be made. Hence, it is almost inevitable that when countries vary in their emphasis on different combinations of skills, this will have a

bearing on their comparative advantages in trade.

The education parameter δ in our model can be interpreted in alternative ways to represent different features of an education system. For example, it is possible to interpret δ as the degree of ability pooling in school, the prevalence of public schools and the degree of income equality. The links between these three factors and skill diversity in a closed economy have been studied extensively in the literature of economics of education.²³ Given our main focus on the dynamics between two sectors and two trading countries, we have chosen not to explicitly model these factors, except for the part captured by δ .²⁴ By focusing on the degree of curriculum centralization, our paper also highlights a distinct aspect of the education system that has not received much attention in the literature but that could exert fundamental effects on a country's talent composition, sectoral specialization, and comparative advantage in trade. That said, it would be interesting in future research to consider a richer model that takes into account multiple features of an education system and to work out their interactions in shaping the talent distribution.

Stable Difference in Education Systems. Our model shows that the contrasting styles of education systems in the US and Japan could be a long-term equilibrium outcome that is compatible with and reinforced by their trade pattern. Their initial difference, which was possibly due to distinct cultural and political contexts, could be moderate but then gets reinforced over time and becomes difficult to reverse (short of dramatic shocks to the trade pattern).

A large degree of decentralization has long been a distinguishing feature of the US education system, and the evolution of this organization structure, dating back to the colonial era, has been “at least partially serendipitous” (Black and Sokoloff 2006). The decentralized structure in financing and administering schools by local or state authorities, through enhanced experimentation and flexibility and focused attention to local environments, has served the US quite well. Though in recent decades there are certain concerns about the relatively low performance of the US students

²³For example, see Bénabou (1996), Epple and Romano (1998), Fernández and Rogerson (1998), and Takii and Tanaka (2009) among others.

²⁴Allowing unequal educational resources to exert extra influence on skill diversity is not likely to change our main results. For example, starting from the same inequality in educational resources in both Japan and US, a higher δ in Japan leads to a more homogenous skill pool, which will then lead to a lower income inequality that in turn contributes to even more homogenous skills in future generations in comparison to the US. Thus, the effect of δ on skill diversity is enlarged by allowing unequal resources.

in international tests compared with other developed countries, and some policies are adopted to address the under-performing poor school districts (Dillon 2007, 2009), it does not appear that the distinctive features of the US education system, such as its decentralized manner, relatively low pressure on students, and emphasis on individual initiative and creativity, will change at all.

As a latecomer in modern education, Japan in the Meiji era experimented with local funding and operation of education “only to discover that the people would not pay, so after only a few years of this experiment, the Meiji state took over the full burden of financing the public school system. ... The reliance on state support was associated with a uniform curriculum, a central system for exams and textbook production, and other centralizing tendencies” that deliver more homogeneous student outcomes than the decentralized US education system (Cummings 1999). Similar experiences were repeated during the American occupation of Japan after the World War II; the decentralization effort initiated by the American was reversed years later to fit traditional Japanese models more closely (Beauchamp 1987). In recent years, in an effort to prevent “cram education” and boost individual potentials and ability to think, Japan has experimented with various teaching methods under the so-called Yutori (Relaxed) Education. However, the new education guidelines have again met with strong resistance from education experts and parents.²⁵ These experiences illustrate the difficulty to reverse the initial pattern of a country’s education style.

6 Concluding Remarks

While the important role of education in enhancing a country’s international competitiveness has been recognized by many countries, the effects of international trade on education policies are not well understood. In an attempt to shed light on this issue, this paper provides a theory on the simultaneous determination of a country’s education system and its comparative advantage in trade. Countries have to face trade-off when choosing a particular style of education system (a more centralized curriculum structure tends to promote talent homogeneity, while a more flexible one encourages talent diversity). Since talent diversity affects industry productivities, the choice of education system will inevitably have a bearing on a nation’s comparative advantage. An interesting

²⁵See for example <http://www.mext.go.jp/english/org/struct/014.htm>, and Takayama (2007).

implication of the paper's analysis is that trade plays an important role in shaping cross-country differences in education systems, because trade enhances countries' incentives to become more specialized in their sector of comparative advantage and to further differentiate their education policies. The empirical analysis based on the TIMSS dataset finds a significant and negative effect of curriculum centralization on talent diversity for participating OECD countries in various years of study, and this supports our theoretical characterization of education systems. The theoretical prediction of a positive relationship between divergence in education systems and increased trade intensity is a hypothesis difficult to verify given the limited data on curriculum centralization, although our preliminary findings are in line with the theory.

The current paper focuses on how the trade pattern and education systems between two advanced industrial economies interact, and how, as a result, persistent differences in education systems across countries arise in the equilibrium. A fruitful topic in future research may be to study how the education system of a country, competing and trading in the world economy, evolves dynamically over time as it advances across development stages. In future work, one may also want to extend the current paper's analysis to allow the education policy to be determined by political economy, where parents express their preferred education system via voting or where industrial interests exert influence on policy makers. Last but not least, as discussed in Section 5, an ambitious but interesting extension could be to allow for multiple features of an education system (e.g., the degree of curriculum centralization, the ratio of public versus private school, or the use of ability streaming), and to study how these factors interact in determining a country's talent diversity and their endogenous equilibrium in open economies.

APPENDIX A: Proofs

Proof of Lemma 2.

Proof. First note that $p \leq p_m$ implies that the mean ability workers are engaged in the auto sector, i.e., $a_m \leq \tilde{a}$. Next, note that $Y_A(p, \delta)$ can be rewritten as

$$\begin{aligned} Y_A(p, \delta) &= \lambda \int_{a_l}^{\tilde{a}} a^\theta f(a) da \\ &= \lambda \int_{a_{l0}}^{\tilde{a}_0} ((1 - \delta)a_0 + \delta a_m)^\theta g(a_0) da_0, \end{aligned}$$

where $\tilde{a}_0 \equiv \frac{\tilde{a} - \delta a_m}{1 - \delta}$, and $f(\cdot)$ and $g(\cdot)$ are the probability density functions corresponding to $F(\cdot)$ and $G(\cdot)$, respectively. We have

$$\begin{aligned} \left. \frac{\partial Y_A}{\partial \delta} \right|_p &= \lambda \theta \int_{a_{l0}}^{\tilde{a}_0} ((1 - \delta)a_0 + \delta a_m)^{\theta-1} (a_m - a_0) g(a_0) da_0 \\ &\quad + \lambda \frac{\partial \tilde{a}_0}{\partial \delta} ((1 - \delta)\tilde{a}_0 + \delta a_m)^\theta g(\tilde{a}_0) \\ &= \frac{\lambda \theta}{(1 - \delta)} \int_{a_l}^{\tilde{a}} a^{\theta-1} (a_m - a) f(a) da \\ &\quad + \frac{\lambda}{(1 - \delta)^2} \tilde{a}^\theta (\tilde{a} - a_m) f(\tilde{a}) > 0. \end{aligned}$$

To see the positive sign, note that the second term is weakly positive, as $a_m \leq \tilde{a}$ for the given price range $p \leq p_m$. Next, note that the first term is positive because

$$\int_{a_l}^{\tilde{a}} a^{\theta-1} (a_m - a) f(a) da > \int_{a_l}^{\tilde{a}} a_m^{\theta-1} (a_m - a) f(a) da > 0,$$

where the first inequality follows because $a^{\theta-1}(a_m - a) > a_m^{\theta-1}(a_m - a)$ holds for any a and any $\theta < 1$: it holds for $a < a_m$, as in this case, $a_m - a > 0$ and $a^{\theta-1} > a_m^{\theta-1}$, and for $a > a_m$, as in this case, $a_m - a < 0$ and $a^{\theta-1} < a_m^{\theta-1}$. The second inequality follows since $\int_{a_l}^{\tilde{a}} a \frac{f(a)}{F(\tilde{a})} da < a_m$.

The effect of δ on Y_S (holding p constant) can be shown in a similar way. Note that $Y_S(p, \delta) =$

$\int_{\tilde{a}}^{a_h} a^\gamma f(a) da = \int_{\tilde{a}_0}^{a_{h0}} ((1-\delta)a_0 + \delta a_m)^\gamma g(a_0) da_0$, and

$$\begin{aligned} \left. \frac{\partial Y_S}{\partial \delta} \right|_p &= \gamma \int_{\tilde{a}_0}^{a_{h0}} ((1-\delta)a_0 + \delta a_m)^{\gamma-1} (a_m - a_0) g(a_0) da_0 \\ &\quad - \frac{\partial \tilde{a}_0}{\partial \delta} ((1-\delta)\tilde{a}_0 + \delta a_m)^\gamma g(\tilde{a}_0) \\ &= \frac{\gamma}{1-\delta} \int_{\tilde{a}}^{a_h} a^{\gamma-1} (a_m - a) f(a) da \\ &\quad - \frac{1}{(1-\delta)^2} \tilde{a}^\gamma (\tilde{a} - a_m) f(\tilde{a}) < 0. \end{aligned}$$

The above negative sign holds because the second term is weakly negative again for the same reason that $a_m \leq \tilde{a}$ for the given price range $p \leq p_m$, and because the first term is negative for

$$\int_{\tilde{a}}^{a_h} a^{\gamma-1} (a_m - a) f(a) da < \int_{\tilde{a}}^{a_h} a_m^{\gamma-1} (a_m - a) f(a) da < 0.$$

The first inequality follows because $a^{\gamma-1} (a_m - a) < a_m^{\gamma-1} (a_m - a)$ holds for any a and any $\gamma > 1$, and the last inequality follows because $\int_{\tilde{a}}^{a_h} a \frac{f(a)}{1-F(\tilde{a})} da > a_m$. ■

Proof of Lemma 3.

Proof. Define $\bar{a} \equiv \int_{a_l}^{\tilde{a}} a \frac{f(a)}{F(\tilde{a})} da$ and $\bar{\bar{a}} \equiv \int_{\tilde{a}}^{a_h} a \frac{f(a)}{1-F(\tilde{a})} da$, and note that $\bar{a} < a_m < \bar{\bar{a}}$. Further note that $F(a_m) = G(a_m) \leq \frac{1}{2}$ by condition (A1). By (11), we have the following condition on the equilibrium price, omitting the decoration to simplify presentations:

$$\begin{aligned} (24) \quad p &= \frac{1-\beta}{\beta} \frac{\lambda \int_{a_l}^{\tilde{a}} a^\theta dF(a)}{\int_{\tilde{a}}^{a_h} a^\gamma dF(a)} < \frac{1-\beta}{\beta} \frac{\lambda \bar{a}^\theta F(\tilde{a})}{\bar{a}^\gamma [1-F(\tilde{a})]} \\ &< \frac{1-\beta}{\beta} \lambda a_m^{\theta-\gamma} \frac{F(\tilde{a})}{[1-F(\tilde{a})]} \leq \lambda a_m^{\theta-\gamma} \frac{F(\tilde{a})}{[1-F(\tilde{a})]}, \end{aligned}$$

where the first inequality follows by the concavity (convexity) of the auto (software) production, the second inequality by the fact that $\bar{a} < a_m < \bar{\bar{a}}$, and the last weak inequality by the condition that $\beta \geq \frac{1}{2}$.

Suppose that $\tilde{a} < a_m$. By (7), this implies that $p > p_m$; on the other hand, by (24) and the condition that $F(a_m) \leq \frac{1}{2}$, this implies that $p < \lambda a_m^{\theta-\gamma} \frac{F(a_m)}{[1-F(a_m)]} \leq \lambda a_m^{\theta-\gamma} \equiv p_m$, a contradiction.

Thus, it must be the case that $a_m \leq \tilde{a}$ at the equilibrium, or equivalently, the price must be such that $p \leq p_m$ at the equilibrium. ■

Proof of Lemma 5.

Proof. Define $V(p, \delta_J, \delta_U) \equiv (1 - \beta) [Y_{AJ}(p, \delta_J) + Y_{AU}(p, \delta_U)] - \beta p [Y_{SJ}(p, \delta_J) + Y_{SU}(p, \delta_U)]$.

Condition (13) implies that $V(\bar{p}, \delta_J, \delta_U) = 0$, based on which we get

$$\frac{\partial \bar{p}}{\partial \delta_J} = - \frac{(1 - \beta) \left. \frac{\partial Y_{AJ}}{\partial \delta_J} \right|_p - \beta p \left. \frac{\partial Y_{SJ}}{\partial \delta_J} \right|_p}{(1 - \beta) \left. \frac{\partial (Y_{AJ} + Y_{AU})}{\partial p} \right|_{p=\bar{p}} - \beta p \left. \frac{\partial (Y_{SJ} + Y_{SU})}{\partial p} \right|_{p=\bar{p}} - \beta (Y_{SJ} + Y_{SU}) \Big|_{p=\bar{p}}} > 0,$$

since $\left. \frac{\partial Y_{AJ}}{\partial \delta_J} \right|_p > 0 > \left. \frac{\partial Y_{SJ}}{\partial \delta_J} \right|_p$ by Lemma 2, and $\frac{\partial Y_{SJ}}{\partial p} > 0 > \frac{\partial Y_{AJ}}{\partial p}$ and $\frac{\partial Y_{SU}}{\partial p} > 0 > \frac{\partial Y_{AU}}{\partial p}$ by (8), (9), and Lemma 1. We can show $\frac{\partial \bar{p}}{\partial \delta_U} > 0$ analogously. ■

APPENDIX B: List of OECD countries participating in TIMSS

OECD countries	TIMSS 1995			TIMSS 1999	TIMSS 2003		TIMSS 2007	
	4th grade	8th grade	End of secondary school	8th grade	4th grade	8th grade	4th grade	8th grade
AUSTRALIA: 1971	o	o	o	o	o	o	o	o
AUSTRIA: 1961	o	o	o				o	
BELGIUM: 1961								
Belgium (Flemish)		o		o	o	o		
Belgium (French)		o						
CANADA: 1961	o	o	o	o				
DENMARK: 1961		o	o				o	
FINLAND: 1969				o				
FRANCE: 1961		o	o					
GERMANY: 1961		o	o				o	
GREECE: 1961	o	o	o					
ICELAND: 1961	o	o	o					
IRELAND: 1961	o	o						
ITALY: 1962	o	o	o	o	o	o	o	o
JAPAN: 1964	o	o		o	o	o	o	o
LUXEMBOURG: 1961								
NETHERLANDS: 1961	o	o	o	o	o	o	o	
NEW ZEALAND: 1973	o	o	o	o	o	o	o	
NORWAY: 1961	o	o	o		o	o	o	o
PORTUGAL: 1961	o	o						
SPAIN: 1961		o						
SWEDEN: 1961		o	o			o	o	o
SWITZERLAND: 1961		o	o					
TURKEY: 1961				o				o
UNITED KINGDOM: 1961								
England	o	o		o	o	o	o	o
Scotland	o	o			o	o	o	o
UNITED STATES: 1961	o	o	o	o	o	o	o	o
CZECH REPUBLIC: 1995	o	o	o	o			o	o
HUNGARY: 1996	o	o	o	o	o	o	o	
KOREA: 1996	o	o		o		o		o
MEXICO: 1994								
POLAND: 1996								
SLOVAK REPUBLIC: 2000		o		o		o	o	
CHILE: 2010				o		o		
SLOVENIA: 2010	o	o	o	o	o	o	o	o

Note: o = participating country. The first column lists OECD member countries and the year when they joined OECD. See <http://nces.ed.gov/timss/countries.asp> for a complete list of participating countries other than OECD members.

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