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On the Origins of Comparative Advantage

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Abstract

This paper proposes a simple theory of international trade with endogenous technological differences across countries. The core of our analysis lies in the determinants of the division of labor. We consider a world economy comprising two large countries, with a continuum of goods and one factor of production, labor. Each good is characterized by its complexity, defined as the number of tasks that must be performed to produce one unit. There are increasing returns to scale in the performance of each task, which creates gains from specialization, and uncertainty in the enforcement of each contract, which create transaction costs. The trade-off between these two forces pins down the size of productive teams across sectors in each country. Under free trade, the country where teams are larger specializes in the more complex goods. In our model, it is the country where the product of institutional quality and human per worker capital is larger. Hence, better institutions and more educated workers are complementary sources of comparative advantage in the more complex industries.

Keywords: Complexity, Institutional Quality, Human Capital,
Division of labor, Comparative Advantage

J.E.L. Classification: F10

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1 Introduction

“Ever since David Ricardo published his *Principles of Political Economy*, cross-country differences in technology have featured prominently in economists’ explanations of the international pattern of specialization and trade. Yet, until quite recently, the formal trade-theory literature has focused almost exclusively on the *effects* of technological disparities without delving too much into their *causes*.” This assessment of the trade-theory literature by GROSSMAN and HELPMAN [1995] appears as relevant today as it was a decade ago. While our understanding of the relationship between technological progress and trade has considerably improved, we still know little about the determinants of productivity differences across countries and industries. The main objective of this paper is to develop a simple theory of international trade that may also shed light on the origins of these differences.

The premise of our analysis is that the extent of the division of labor is a key determinant of productivity, as first emphasized by SMITH [1776].² We enrich this fundamental insight by modeling formally the channels through which the division of labor is itself determined. Our analysis emphasizes two forces: (i) gains from specialization; and (ii) transaction costs. As in Smith’s pin factory, these gains derive from increasing returns to scale in production. Their magnitude, however, crucially depends on the *complexity* of the production process, which is a function of an industry’s technology. Transaction costs, on the other hand, come from imperfect contract enforcement, as convincingly argued by NORTH [1990].³ In our model, they vary with *institutional quality* and *human capital per worker*, which are characteristics of countries.

The basic logic of our trade theory can be sketched as follows. First, the trade-off between gains from specialization and transaction costs pins down the extent of the division of labor across sectors in each country. Second, endogenous differences in the optimal organization of production determine the pattern of trade. Though simple, this two-step-approach allows us to generate new predictions on the determinants of international trade. By offering a closer look at the origins of technological differences, we find that better institutions and higher levels of educa-

²In the opening sentence of the *Wealth of Nations*, Adam Smith notes: “The greatest improvement in the productive powers of labour, and the greater part of the skill, dexterity, and judgment with which it is any where directed, or applied, seem to have been the effects of the division of labour.”

³“One cannot take enforcement for granted. It is (and has always been) the critical obstacle to increasing specialization and division of labor”; NORTH [1990].

tion are complementary sources of comparative advantage in the more complex industries.

Section 2 illustrates some of the main ideas of our analysis through a simple example. Our formal model is described in section 3. We consider a world economy comprising two large countries, with a continuum of goods and workers.⁴ All workers are endowed with the same amount of labor, which captures the level of education in a given country. The production of every good requires that a set of elementary tasks be performed. As previously mentioned, there are increasing returns to scale in the performance of each task: before being able to perform a task, workers must spend a fixed amount of time learning it. Goods differ in their complexity, defined as the number of elementary tasks that must be performed to produce one unit. The more complex a good is, the longer it takes to learn how to perform all tasks, and the larger are the gains from the division of labor.

In each industry, contracts organize productive activities by assigning elementary tasks to workers. But, their enforcement is imperfect. If the contract of a worker is enforced, she performs her tasks in accordance with the terms of her contract; otherwise, she does not perform at all. A key parameter of the model is the probability with which a given contract is enforced. This probability is assumed identical across industries and aims to capture institutional quality, that is the efficiency of the judicial system and/or the level of trust in a given country.

Section 4 characterizes the efficient organization of production. Our analysis of the extent of the division of labor builds on previous works by BECKER and MURPHY [1992] and KREMER [1993]. It predicts that team size—formally, the number of workers who cooperate on each unit of a given good—increases with institutional quality and complexity, but decreases with human capital per worker.

Section 5 analyzes the pattern of trade between two countries, which share the same technological know-how, but differ in the quality of their institutions and the human capital of their workers. Because there are increasing returns to scale in the performance of each task, the country with larger teams—in efficiency units of labor—specializes in the more complex goods under free trade. In our model, it is the country where the product of institutional quality and workers’ human capital is

⁴For expositional purposes, we always refer to economic agents as “workers”, but they may be “independent contractors” as well. Our model is agnostic about whether the division of labor takes place within or outside the boundary of the firm.

larger. Hence, better institutions and higher levels of human capital are complementary sources of comparative advantage in the more complex industries.

Section 6 uses this qualitative insight to identify in the data which countries have—according to our theory—better institutions. Our empirical strategy is simple. First, we identify which countries have a comparative advantage in the more complex industries. Second, we estimate the pattern of comparative advantage predicted by the cross-country variation in human capital. Finally, we infer countries’ institutional quality from the difference between their actual and their predicted pattern of exports.

Our paper makes two distinct contributions to the existing trade literature. First, it contributes to the recent, but rapidly growing, literature on international trade and institutions; see e.g. ACEMOGLU et al. [2006], CUNAT and MELITZ [2006], LEVCHENKO [2004], MATSUYAMA [2005], NUNN [2005], and VOGEL [2004]. The starting point of these papers is the same as ours. While a given institutional characteristic may affect productivity in *all* sectors, it presumably affects it relatively more in *some* sectors, hence the pattern of comparative advantage. Our paper differs significantly, though, in terms of the specific mechanism through which institutions affect productivity, and in turn, international trade.

Our model introduces complexity as the main source of “institutional dependence” across industries. The logic—inspired by SMITH [1776] and NORTH’s [1990] fundamental insights—is simple and intuitive: larger gains from specialization imply more workers per team, and so more contracts to be enforced. Building on this idea, we are able to generate new predictions on the pattern of international trade, which we use to measure institutional quality. Unlike previous papers, we do not try to test a particular trade theory by using existing proxies of institutional quality. Instead, we let trade data tell us which countries have—according to our theory—better institutions.

Focusing on the endogenous organization of production presents another advantage. It allows us to develop a single trade model where both institutions and education interact to determine the pattern of trade. Hence, our paper also contributes to the recent literature on international trade and human capital; see e.g. GROSSMAN and MAGGI [2000], GROSSMAN [2004], and OHNSORGE and TREFLER [2004]. The previous papers show that not only aggregate factor endowments, but also the dispersion of these factors across workers can be a source of comparative

advantage. Our theory shows that when there are gains from specialization and transaction costs, factor endowments *per* worker also matter for the pattern of trade. By going beyond the “black-box” of aggregate production functions, our model is able to shed light on another channel through which individual differences in human capital may affect trade flows across countries.⁵

2 A Simple Example

Some of the main ideas of our analysis are best illustrated by a simple example. Consider an island economy with two sectors: pins and computers. The island is populated by many identical workers, each able to work for 300 days. In each industry, producing one unit of output requires many complementary tasks to be performed; and whatever the task is, it takes a worker 1 day to learn it and 1 more day to perform it.⁶ But, computers are more *complex* than pins: it takes 10 tasks to produce a pin, against 100 to produce a computer.

In both industries, goods can be produced by teams of 1 or 2 workers. For each worker, there is a contract that stipulates her assignment of tasks. However, such contracts are not perfectly enforced. Only 90% of the workers fulfill their contractual obligations; the remaining 10% do not perform any tasks. Given the technological and institutional constraints of the island, what is the efficient team size in the pin and computer industries, respectively?

Consider first the pin industry. If there is 1 worker per team, then this worker needs 10 training days to learn how to produce a pin from the beginning to the end. Instead, if there are 2 workers per team, then each worker may specialize in only 5 tasks, and spend 5 more days producing rather than learning. The 5 days that are saved for production by adding an extra worker captures the gains from specialization. What are the associated transaction costs? While a team with a single worker has a 90% chance to produce, a team with 2 specialized workers needs both of them to perform, and so produces with probability 81%. Specialization increases the number of contracts that need to be simultaneously enforced, which reduces the expected output of each team. In the pin industry, this second effect is dominant. If teams are of size 1, each worker may produce for $300 - 10 = 290$ days, with probability 90%. If teams are of size 2, each worker may produce for $300 - 5 = 295$ days,

⁵Our analysis is also related, though less closely, to ANTRAS et al. [2006] who investigate the relationship between the distribution of human capital and offshoring.

⁶In other words, it takes 3 days for a given worker to perform the same task twice.

but with probability 81%. Since $0.9 \times 290 = 261 > 0.81 \times 295 = 238.95$, the efficient team size in the pin industry is equal to 1.

Let us now turn to the computer industry. If there are 2 workers per team, then each worker may save 50 training days. While there are gains from specialization in both industries, these gains are 10 times larger in the computer industry. Thus for given transaction costs, its teams ought to be larger. Indeed, in a team of size 1, each worker may produce for $300 - 100 = 200$ days, with probability 90%; in a team of size 2, each worker may produce for $300 - 50 = 250$ days, with probability 81%. Since $0.9 \times 200 = 180 < 0.81 \times 250 = 202.5$, the efficient team size in the computer industry is equal to 2.

This, in a nutshell, explains why the division of labor should be more extensive in the more complex industries. What does this example tell us about differences in team size across countries? Two things: (i) countries with worse institutions should have smaller teams; and (ii) countries with higher levels of education should have smaller teams. To see this, suppose that *institutional quality* in the island goes down. A given contract now is enforced with a 50% chance. In this case, gains from specialization are unchanged, but transaction costs go up, and so team size decreases. Since $0.5 \times 200 = 100 > 0.25 \times 250 = 62.5$, the efficient team size in the computer industry goes down from 2 to 1. Similarly, suppose that *human capital per worker* goes up. The same 300 working days now are worth 600 days. Then, team size also decreases from 2 to 1 in the computer industry, since $0.9 \times 500 = 450 > 0.81 \times 550 = 445.5$. Again, gains from specialization are unchanged, but transaction costs go up—there is more to lose when contracts are not enforced—and so team size decreases.

Suppose now that the island opens up to trade. Its trading partner shares the same technology, but differs in the quality of its institutions and the levels of human capital of its workers. Which of the two islands, if any, should specialize in the computer industry? Our answer is simple: it is the island where teams are larger in efficiency units under autarky, i.e. the island where the number of working days per team is larger.

In the first island, we know that teams in the pin industry comprise 1 worker, endowed with 300 working days. Hence, there are 300 efficiency units per team in this sector. Similarly, teams in the computer industry comprise 2 workers, and so $2 \times 300 = 600$ efficiency units. Let us assume that in the second island, there are 300 efficiency units per team in both industries. This may correspond to one of these two cases: (i) workers in

the second island are endowed with the same amount of human capital, but worse institutions have lead to teams of size 1 in both sectors; or *(ii)* workers' endowments in the second island only are half what they are in the first island, but better institutions have lead to teams of size 2. In any case, the first island has a comparative advantage in the computer industry.

To see this, let us define a_p^1 and a_c^1 as the average number of days necessary to produce one pin and one computer in the first island. Since there is 1 worker per team in the pin industry, we have: $a_p^1 = \frac{300}{\frac{290 \times 0.9}{10}} = 11.5$. In the computer industry, there are 2 workers per team and so: $a_c^1 = \frac{600}{\frac{500 \times 0.81}{100}} = 148$. In turn, the relative unit labor requirement is given by: $\frac{a_c^1}{a_p^1} = 12.8$. Now, let us define a_p^2 and a_c^2 as the average number of days necessary to produce one pin and one computer in the second island. Similar computation leads to: $\frac{a_c^2}{a_p^2} = 14.5 > 12.8 = \frac{a_c^1}{a_p^1}$. The pattern of trade follows. In the island where teams are larger in efficiency units, fixed learning costs can be spread over larger amounts of output. As a result, this island produces and exports computers, which are associated with larger learning costs.

This simple example illustrates two ideas: *(i)* differences in institutions and human capital per worker lead to differences in the optimal organization of production across countries; and *(ii)* these endogenous differences confer distinct comparative advantages. In particular, the country with larger teams in efficiency units has a comparative advantage in the more complex goods. This is valuable information, but by no means the end of the story. One fundamental question remains: what is the country with larger teams in efficiency units? The previous example only suggests that it might be the country with better institutions or lower levels of human capital, because it has more workers per team; or on the contrary, the country with higher levels of human capital, because workers have larger endowments in efficiency units. In order to give a satisfactory answer to this question, we need a formal model to which we now turn.

3 The Model

We consider a world economy comprising two countries, indexed by $c = 1, 2$, and a continuum of industries, indexed by $i \in [0, 1]$.

Endowments. Each country is populated by continuum of workers indexed by $n \in [0, L_c]$. Workers are perfectly mobile across industries and immobile across countries. There are no other factors of production.

All workers in country c are endowed with h_c efficiency units of labor, to which we refer as *human capital per worker*.

Demand. Following DORNBUSCH et al. [1977], we assume that workers in the two countries aim to maximize the same Cobb-Douglas utility function. Hence, the world demand D^i for good $i \in [0, 1]$ is given by

$$p^i D^i = b^i (w_1 L_1 + w_2 L_2) \quad (1)$$

where $p^i > 0$ is the price of good i ; $b^i > 0$ is the constant expenditure share on good i , with $\int_0^1 b^i di = 1$; and w_1 and w_2 are the wages per worker in country 1 and 2, respectively.

Technology (I) — Complementarity. In each industry, a continuum of complementary tasks $t \in [0, z^i]$ must be performed in order to produce one unit of good i . We refer to the number of tasks, $z^i > 0$, as the *complexity* of the production process in industry i . For expositional purposes, we assume that z^i is continuous and strictly increasing in i . The output of good i is given by

$$Q^i = \int_0^{+\infty} \left[\int_0^{z^i} q^i(t, u)^{\frac{\sigma_i - 1}{\sigma_i}} dt \right]^{\frac{\sigma_i}{\sigma_i - 1}} du \quad (2)$$

where $q^i(t, u)$ is equal to 1 if task t is performed on the u -th unit of good i , and zero otherwise. To capture the fact that every task must be performed, we assume that the elasticity of substitution $\sigma_i < 1$ for all i . If task t is not performed on unit u , then this unit is not produced. Note that task performance is “unit-specific”. According to Equation (2), a task which is supposed to be performed on unit u cannot be used on unit $u' \neq u$. We come back to this assumption in the next section.

Technology (II) — Increasing Returns. There are increasing returns to scale in the performance of each task. The amount of labor $l^i(n, t)$ required by a worker n performing task t —at least once—in industry i is given by

$$l^i(n, t) = \int_0^{+\infty} q^i(n, t, u) du + f(t) \quad (3)$$

where $q^i(n, t, u)$ is equal to 1 if worker n performs task t on the u -th unit of good i , and zero otherwise. We interpret the fixed overhead cost $f(t) > 0$ as the time necessary to learn how to perform task t . In the rest of this paper, we assume that $f(t)$ is identical across tasks, and

normalize it to 1. Hence, the total training costs in industry i are equal to $\int_0^{z^i} f(t)dt = z^i$. The more complex a good is, the longer it takes to learn how to produce it, and the larger are the gains from the division of labor.⁷

Firms, Jobs, and Contracts. In each country c and industry i , there is a large number of price-taking firms. Firms can organize their production by designing a set of jobs, J , hiring a set of workers, L , and writing contracts, C , that assign workers to these jobs for each unit they want to produce. Formally, we assume that each firm has 3 control variables:

1. A partition $J = \{J_k\}_{k=1}^N$ of the set of tasks $[0, z^i]$;
2. A subset $L \subset [0, L_c]$;
3. A mapping $C(\cdot, \cdot) : L \times \mathbb{R}^+ \rightarrow \{J, \emptyset\}$.

The number of distinct jobs, N , measures the extent of the division of labor. In the remainder of this paper, we refer to N as *team size*. This is the key endogenous variable in our model. Note that the set of jobs J may not vary with u . Although we do not impose restrictions on how a particular unit is produced, we require that all units be produced the same way. For simplicity, we also assume that: (i) once hired by a firm, workers get paid w_c irrespective of the number of tasks they perform; and that: (ii) firms cannot assign more than 1 worker to the same job on any given unit. We denote $n_k(u) \in \{L, \emptyset\}$ the worker (if any) assigned to the k -th job on unit u .

Institutions. We focus on a single, but crucial, function of institutions: contract enforcement. Our starting point is that better institutions—either formal or informal—increase the probability that contracts are enforced. If $\theta_c \geq 0$ is the *quality of institutions* in country c , then for any $n \in [0, L_c]$, we assume that

$$q^i(n, t, u) = \mathbb{I}\{t \in C(n, u)\} \text{ for all } t \in [0, z^i] \text{ and } u \in \mathbb{R}^+,$$

⁷Strictly speaking, complexity measures the number of tasks necessary to produce one unit of output. All tasks are identical, but more complex goods require more tasks. Alternatively, one could assume that all goods require the same number of tasks, but that some tasks take more time to be learnt than others. Then, more complex goods would be the ones associated with more complicated tasks. It should be clear that these two approaches are equivalent; in any case, total training costs solely determine the magnitude of the gains from specialization.

with probability $e^{-\frac{1}{\theta_c}}$, and

$$q^i(n, t, u) = 0 \text{ for all } t \in [0, z^i] \text{ and } u \in \mathbb{R}^+,$$

with probability $1 - e^{-\frac{1}{\theta_c}}$. When $\theta_c = 0$, institutions are completely inefficient and workers never perform any task. When $\theta_c = \infty$, institutions are perfect, and like in the neoclassical benchmark, workers perform the tasks stipulated in their contracts with probability 1.

A few comments are in order. First, we restrict ourselves to situations where the contract of a given worker n is either enforced on all tasks and all units or not enforced at all. If a worker shirks on one assignment of tasks, she shirks on all of them.⁸ Second, we rule out any interaction across workers. Each worker randomly performs her assignment of tasks with probability $e^{-\frac{1}{\theta_c}}$, irrespective of the performance of other workers. Finally, we treat imperfect contract enforcement as an additional technological constraint. In our model, θ_c is an exogenous parameter, not a control variable.⁹

4 The Organization of Production

This section focuses on the supply-side of the economy. We first describe the optimization program of a representative firm, and then derive the restrictions that profit maximization imposes on the organization of production. Demand and market clearing conditions will be introduced in Section 5.

4.1 The Firm's Problem

Consider a representative firm in industry i and country c , taking as given the price, p^i , the wage, w_c , and the resource constraint of each worker. The optimization program of a firm maximizing its expected profits is given by

$$\begin{aligned} \max_{J, L, C} \Pi &\equiv p_i E(Q^i) - \int_{n \in L} w_c dn & \text{(P)} \\ \text{subject to: } &\int_0^{z^i} l^i(n, t) dt \leq h_c \text{ for all } n \in L \end{aligned}$$

⁸This is reminiscent of repeated games à la BERNHEIM and WHINSTON [1990]. In a model where enforcement depends on firms' trigger strategies, firms punish as much as possible, and in turn, workers shirk as much as possible

⁹There is, however, a fundamental difference between the notions of "Technology" and "Institutions" on which our trade model builds. While the same technological know-how may be available in different countries—a firm may simply set up a new plant abroad—institutions are intrinsically country-specific.

The technological and institutional constraints described in Section 3 determine expected output as a function of J , L , and C . Using Equation (2) and $\sigma^i < 1$, $E(Q^i)$ can be simplified into

$$E(Q^i) = \int_{u \in U} E[q^i(u)] du \quad (4)$$

where $U \equiv \{u \in \mathbb{R}^+ | n_k(u) \neq \emptyset \text{ for all } k = 1, \dots, N\}$ is the set of *potential units*, i.e. the units that can be produced were all contractual obligations fulfilled; and $q^i(u)$ is an indicator variable that takes value 1 if all team members, $\{n_1(u), \dots, n_N(u)\}$, perform their jobs on unit u , and 0 otherwise. Since each contract is randomly enforced with probability $e^{-\frac{1}{\theta c}}$, we obtain

$$\begin{cases} q^i(u) = 1, & \text{with probability } e^{-\frac{N}{\theta c}}; \\ q^i(u) = 0, & \text{with probability } 1 - e^{-\frac{N}{\theta c}}. \end{cases} \quad (5)$$

In our model, profit-maximizing firms face a simple trade-off. By having a large number of jobs, N , they can reduce training costs per worker, and in turn increase the number of potential units in U . However, specialization also raises the number of contracts that need to be simultaneously enforced, which reduces the probability, $e^{-\frac{N}{\theta c}}$, that each potential unit gets produced, and decreases expected output.

The existence of the previous transaction costs relies on 2 features of the production function: (i) all tasks are unit-specific; and (ii) all tasks are essential. If firms could freely combine jobs performed on different units or if all tasks were perfect substitutes,¹⁰ the expected output $E(Q^i)$ would depend on $e^{-\frac{1}{\theta c}}$ —the probability that a given *worker* performs her job—rather than $e^{-\frac{N}{\theta c}}$ —the probability that a given *team* performs. In such environments, there would be no costs associated with the division of labor and all workers would specialize in one elementary task t . We view the functional form imposed in Equation (2) as a convenient way to depart from this extreme prediction.

4.2 The Solution

We solve the firm's maximization program in 2 steps. First, we characterize the contracts and jobs that maximize expected profits, taking N and L as given. This gives us the number of potential units, $\bar{U}(N, L)$,

¹⁰If there exist 2 groups of tasks, those that are perfect substitutes and those that are perfect complements, then our analysis is unchanged. One just need to bundle tasks that are perfect substitutes together into one essential task, then all tasks are perfect complements.

chosen by a profit-maximizing firm. Second, we use this expression to compute the optimal values of N and L .

Step I. We decompose the first part of our analysis into 3 lemmas. The formal proofs of Lemmas 1 and 2 can be found in Appendix A.

Lemma 1 *Suppose that J^* and C^* are a solution of (P). Then for all $n \in L$, $\exists k = 1, \dots, N$ such that $C^*(n, u) \in \{J_k^*, \emptyset\}$ for all $u \in \mathbb{R}^+$.*

Lemma 1 states that all workers specialize in 1 job. The intuition is simple. Since team size is equal to N , all units are produced with the same probability $e^{-\frac{N}{\theta_c}}$. In order to maximize expected profits, firms must therefore maximize the number of potential units in U . This is achieved by minimizing training costs per worker. Hence, workers who know how to perform 1 job should perform it as many times as possible.

Lemma 2 *Suppose that J^* is a solution of (P). Then for all $k = 1, \dots, N$, J_k^* is such that $\int_{t \in J_k^*} dt = \frac{z^i}{N}$.*

Lemma 2 states that all jobs include the same number of tasks. Lemma 2 builds on the following observation. A marginal decrease in the number of tasks z included in a job increases the number of potential units, $\frac{h_c - z}{z}$, that workers specializing in that job can participate in. However, this increase is larger for jobs with more tasks; in our model, $\frac{h_c - z}{z}$ is convex in z . Since profit maximization requires marginal changes in workers' productivity to be equalized across jobs, it also requires each job to include the same number of tasks.

According to Lemmas 1 and 2, all workers have $h_c - \frac{z^i}{N}$ units of labor available for production in country c and industry i . Using this insight, we can derive the number of potential units, $\bar{U}(N, L)$, chosen by a profit-maximizing firm with N jobs and a set of workers L .

Lemma 3 *Suppose that J^* and C^* are a solution of (P). Then, $\bar{U}(N, L)$ is given by*

$$\bar{U}(N, L) = \int_{n \in L} \left(\frac{h_c}{z_i} - \frac{1}{N} \right) dn \quad (6)$$

In our set-up, all jobs are necessary to produce one unit. So, a profit-maximizing firm must allocate the same amount of labor, $(1/N) \cdot \int_{n \in L} \left(h_c - \frac{z^i}{N} \right) dn$, to each job. Since each jobs includes z^i/N tasks, we directly get Equation (6).

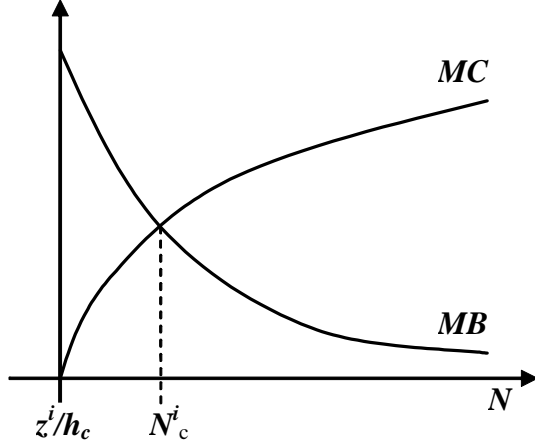


Figure 1: Optimal Team Size

Note that $\bar{U}(N, L)$ is maximized when N is infinite and every worker only learns an infinitesimal task. In other words, if tasks always are performed, efficiency requires each skill to be used as intensively as possible. This is in the spirit of ROSEN [1983].

Step II. We may now compute the optimal values of N and L . Using Equations (4), (5), and (6), we can rearrange the firm's maximization as

$$\max_{N, L} \int_{n \in L} \left[p_i e^{-\frac{N}{\theta_c}} \left(\frac{h_c}{z_i} - \frac{1}{N} \right) - w_c \right] dn$$

Let us denote N_c^i the optimal team size in industry i and country c . By definition, N_c^i must satisfy the following first-order condition:

$$\frac{z^i}{(N_c^i)^2} = \frac{1}{\theta_c} \left(h_c - \frac{z^i}{N_c^i} \right) \quad (7)$$

$MB \equiv \frac{z^i}{N^2}$ corresponds to the marginal benefit of increasing team size. It is equal to the extra units of labor that workers are able to spend performing tasks, rather than learning them. $MC \equiv \frac{1}{\theta_c} \left(h_c - \frac{z^i}{N} \right)$ corresponds to the marginal cost of increasing team size. It is equal to the extra units of labor that are lost when contracts are not enforced. Equation (7) states that when team size is chosen optimally, the marginal gains from the division of labor are equal to the transaction costs they create. This is described graphically in Figure 1.

We can solve Equation (7) explicitly. In our model, N_c^i is uniquely determined as a function of complexity, z^i , institutional quality, θ_c , and

human capital per worker, h_c :

$$N_c^i = \frac{z^i}{2h_c} \left(1 + \sqrt{1 + \frac{4\theta_c h_c}{z^i}} \right) \quad (8)$$

In order to conclude our analysis of the solution of the firm's problem, we note that N_c^i does not depend on L . This means that—once jobs and contracts are set optimally—there are constant returns to scale at the firm level: the expected output of a firm doubles when it doubles its employment. This directly implies that the optimal mass of workers is: indeterminate if the real wage, w_c/p^i , is equal to expected output per worker, $e^{-\frac{N_c^i}{\theta_c}} \cdot \left(\frac{h_c}{z^i} - \frac{1}{N_c^i} \right)$; equal to 0 if it is strictly higher; and equal to $+\infty$ if it is strictly lower.

4.3 Comparative Statics

We can use Equation (8) to undertake comparative static analysis. The main predictions of our theory on the determinants of the division of labor are summarized in Proposition 1.

Proposition 1 *The extent of the division of labor: (i) increases with institutional quality, θ_c ; (ii) increases with complexity, z^i ; and (iii) decreases with human capital per worker, h_c .*

As previously mentioned, the extent of the division of labor, N_c^i , depends on the trade-off between gains from specialization and transaction costs. In Figure 1, the MB curve captures the marginal gains of increasing team size, and the MC curve its marginal costs. When institutional quality improves, transaction costs decrease at the margin— MC shifts down—and team size increases. Similarly, as the complexity of an industry increases, marginal gains from specialization increase— MB shifts up—and transaction costs decrease at the margin— MC shifts down,¹¹ which both increase team size. Since N_c^i only depends on z^i and h_c through their ratio, an increase in workers' human capital is equivalent to a decrease in the good's complexity. As a result, team size decreases with human capital per worker.

5 Free Trade Equilibrium

5.1 Definition

Before defining a free trade equilibrium for our economy, we make a few simple observations. First, since there are constant returns to scale at the

¹¹More complex goods are associated with larger training costs. So, when complexity increases, the number of potential units decreases, and the loss of expected output associated with a marginal increase in team size decreases as well.

firm level, we can describe the production possibility frontiers of the two countries as in DORNBUSCH et al. [1977]. In our set-up—once jobs and contracts have been set optimally—the constant unit labor requirement, a_c^i , in country c and industry i is given by

$$a_c^i = \left[e^{-\frac{N_c^i}{\theta_c}} \cdot \left(\frac{h_c}{z_i} - \frac{1}{N_c^i} \right) \right]^{-1} \quad (9)$$

where N_c^i is the optimal team size; see Equation (8). Second, the equality of supply and demand for all goods $i \in [0, 1]$ requires zero profits under constant returns to scale. This implies

$$p^i/w_c \leq a_c^i \quad (10)$$

with strict equality if good i is produced in country c . Condition (10) simultaneously pins down the price of good i and the country where it is produced, as a function of the wages w_1 and w_2 in the two countries. Third, the equilibrium of the labor market in country c requires

$$\int_{i \in S_c} b^i (w_1 L_1 + w_2 L_2) di = w_c L_c \quad (11)$$

where $S_c \subset [0, 1]$ is the set of goods produced and exported by country c .¹² This last equation pins down the relative wage $\omega \equiv \frac{w_1}{w_2}$, as a function of the pattern of international specialization.

Based on the previous discussion, we define a free trade equilibrium for our economy as follows.

Definition 1 *A free trade equilibrium is a continuum of prices p^i for all $i \in [0, 1]$; a pair of wages w_1 and w_2 ; a pattern of international specialization described by S_1 and S_2 ; a continuum of team sizes N_c^i for all $i \in [0, 1]$ and $c = 1, 2$, such that: (i) firms maximize their expected profits, Equation (8); (ii) firms make zero profits, Condition (10); and (iii) labor markets clear in every country, Equation (11).*

5.2 The Origins of Comparative Advantage

The pattern of comparative advantage in our model is determined—like in any other Ricardian model—by differences in labor productivity across countries and industries. The contribution of our paper is to offer

¹²For expositional purposes, we ignore situations where the same good is simultaneously produced in country 1 and country 2. In a free trade equilibrium, the set of goods for which this may occur will be of measure zero.

a trade theory that also is able to explain where these differences come from, namely the origins of comparative advantage.

The Main Result. Let us denote $A(z^i; \theta_1, h_1, \theta_2, h_2) \equiv \frac{a_2^i}{a_1^i}$ the relative unit labor requirement function which is at the heart of the standard Ricardian model. Equation (9) implies

$$A(z^i; \theta_1, h_1, \theta_2, h_2) = \frac{h_2 N_2^i e^{\frac{N_2^i}{\theta_2}} (h_1 N_1^i - z^i)}{h_1 N_1^i e^{\frac{N_1^i}{\theta_1}} (h_2 N_2^i - z^i)} \quad (12)$$

where N_1^i and N_2^i are given by Equation (8).

Equation (12) allows us to analyze how institutions and human capital per worker endogenously determine the pattern of comparative advantage. The main result of our paper is presented in Proposition 2. As before, the formal proof can be found in Appendix A.

Proposition 2 *A is strictly increasing in z^i if and only if $\theta_1 h_1 > \theta_2 h_2$.*

Proposition 2 states that the country where the product of institutional quality and human capital per worker is higher has a comparative advantage in the more complex industries. The logic is the following. An increase in complexity, z^i , affects the unit labor requirement, a_c^i , in two ways. First, it directly increases the average labor cost of a potential unit, $AC = \frac{z^i h_c N_c^i}{h_c N_c^i - z^i}$; second, it increases team size. When team size is optimal, the latter, however, is a second-order effect. This means that the increase in a_c^i only depends on the increase in AC , and in turn, on the teams' workforce measured in efficiency units, $h_c N_c^i$. If $h_c N_c^i$ is larger, then workers' output on each task is larger as well. As a result, increasing the magnitude of fixed training costs lowers their output relatively less, which raises AC relatively less. This implies that the increase in unit labor requirements is relatively smaller in the country with larger teams in efficiency units. By Equation (8), we know that this is the country where the product of institutional quality and human capital per worker is larger.

Comments. Although both institutional quality and human capital per worker are independent sources of comparative advantage, they determine the pattern of comparative advantage in two very different ways. Institutional quality θ_c only has an indirect effect on the pattern of comparative advantage, through its impact on the optimal team size N_c^i . If team size was exogenously given, then differences in institutions across

countries would have no effect on the pattern of trade. Formally, the monotonicity of $A(z^i; \theta_1, h_1, \theta_2, h_2)$ would be independent of θ_1 and θ_2 ; see Equation (12). In our model, it is the endogenous response of the division of labor that makes institutions a source of comparative advantage.

By contrast, human capital per worker h_c has both a direct and an indirect effect on the pattern of comparative advantage. Besides its impact on N_c^i , it mechanically increases the teams' workforce in efficiency units. Thus, even if N_c^i was exogenously given, cross-country differences in human capital would still affect the pattern of comparative advantage. When workers are more educated, they spend a smaller fraction of their time learning, and so unit labor requirements are lower; see Equation (9). Furthermore, this decrease is not uniform across goods. In the more complex sectors, learning costs are more important and the decrease in unit labor requirements is larger. As a result, the country with more educated workers is relatively more efficient in the more complex industries. Does the endogeneity of the division of labor affect this pattern? The answer is no. When the extent of the division of labor is endogenous, higher levels of human capital also decrease N_c^i , but Equation (8) guarantees that this indirect effect is always dominated by the direct effect: $h_c N_c^i$ increases with h_c .

Compared to the standard Ricardian model, an increase in workers' labor endowments is *not* equivalent to an increase in country size, L_c . In our model, higher values of h_c confer comparative advantage in the more complex sectors. Even if they share the same technology and institutions, a country with one billion workers and a country with one hundred million workers, each of them ten times more productive, are economically distinct trading partners, with distinct comparative advantage. By focusing on individual rather than aggregate levels of human capital, our theory generates a new channel—distinct from the Heckscher-Ohlin model—through which cross-country differences in education levels may affect the pattern of trade.

At this point, it is worth emphasizing a key difference between our approach and GROSSMAN and MAGGI [2000], GROSSMAN [2004], and OHNSORGE and TREFLER [2004]. In our economy, workers from the same country are all identical. Human capital per worker only acts as a determinant of labor productivity. By contrast, worker heterogeneity is at the heart of the aforementioned papers. They assume that technologies are identical across countries, but allow endowments of human capital to differ across workers. In their model, it is the *sorting* of dif-

ferent workers into different industries, which makes the *distribution* of human capital across workers a source of comparative advantage.

Finally, note that Proposition 2 predicts that institutional quality and human capital per worker have complementary effects on the pattern of comparative advantage. Since θ_c and h_c affect A through their product, improvements in institutions have larger effects in countries with more educated workers. Similarly, improvements in education have larger effects in countries with better institutions.

5.3 The Pattern and Consequences of Trade

Having established how the pattern of comparative advantage is endogenously determined in our economy, we can characterize the free trade equilibrium as in DORNBUSCH et al. [1977]. Without loss of generality, we assume that country 1 has a comparative advantage in the more complex industries:

$$\theta_1 h_1 > \theta_2 h_2$$

So, A is strictly increasing in z^i by Proposition 2.

International Specialization. The monotonicity of A allows us to characterize the pattern of international specialization in a straightforward manner. Irrespective of the relative wage $\omega \equiv \frac{w_1}{w_2}$ in equilibrium, there must be a complexity level $\tilde{z} > 0$ such that

$$\omega = A(\tilde{z}) \tag{13}$$

By construction, $A(z^i) < \omega$ if and only if $z^i < \tilde{z}$. Condition (10) therefore implies that in a free trade equilibrium:

$$\begin{aligned} S_1 &= \{i \in [0, 1] \mid z > \tilde{z}\} \\ S_2 &= \{i \in [0, 1] \mid z < \tilde{z}\} \end{aligned}$$

Condition (10) also implies that the equilibrium prices of goods in S_1 and S_2 are given by $w_1 a_1^i$ and $w_2 a_2^i$, respectively.

Labor Market Equilibrium. By Walras' law, we can focus on the labor market in country 2. Rearranging Equation (11), we get

$$\omega = \frac{L_2}{L_1} \cdot \left[\frac{1 - \vartheta(\tilde{z})}{\vartheta(\tilde{z})} \right] \equiv B(\tilde{z}) \tag{14}$$

where $\vartheta(\tilde{z}) \equiv \int_{i \in S_2} b^i di$ is the share of income spent on goods from country 2. Since z^i is continuous and strictly increasing in i , B is strictly

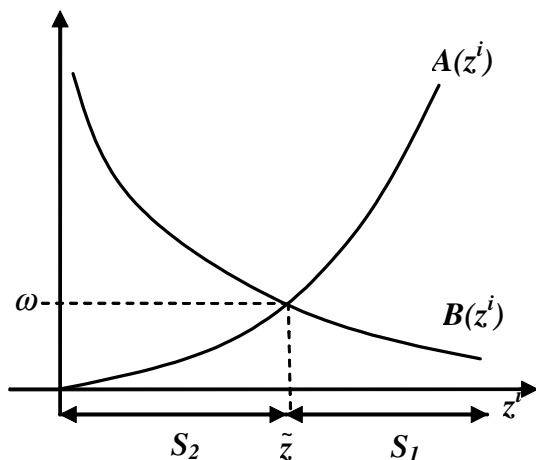


Figure 2: The Pattern of Trade

decreasing in \tilde{z} . Intuitively, an increase in the range of goods produced in country 2 raises, at constant wages, the demand for labor in country 2. Thus a rise in w_2 —i.e. a decrease in ω —is required to maintain the equality between demand and the existing labor supply, L_2 .

Predictions. Equations (13) and (14) jointly determine the relative wage, ω , and the cut-off, \tilde{z} ; see Figure 2. This completes our analysis of a free trade equilibrium. Our findings are summarized in Proposition 3.

Proposition 3 *In a free trade equilibrium, country 1 produces and exports the more complex goods; country 2 produces and exports the less complex ones.*

The welfare impact of trade is straightforward. Compared to autarky, the real wage $\frac{w_1}{p^i}$ is identical for goods whose production remains in country 1 in a free trade equilibrium. However, it goes up for goods whose production shifts to country 2. (Otherwise, they would still be produced in country 1.) The same reasoning applies to the real wage $\frac{w_2}{p^i}$ in country 2. Thus, both countries gain from trade.¹³ The pattern of specialization between developed and developing countries also is clear.

¹³In a previous version of the paper, we also consider the impact of *changes* in institutional quality and human capital per worker in the two countries. Our results echo the analysis of technological progress in KRUGMAN [1986]. When improvements in institutions and education occur in the developed country, both countries gain. But when they occur in the developing country, the developed country might be harmed.

Countries with worse institutions *and* less educated workers specialize in the less complex goods.

We can also analyze the impact of trade on team size by combining Propositions 1 and 3. The prediction again is unambiguous: international trade decreases average team size in developing countries, while increasing it in developed countries. In our model, trade does not change *how* goods are produced in each country. Technological and institutional constraints fully characterize the team size that maximize expected profits; see Equation (8). But by changing *which* goods are produced, trade affects the overall distribution of team size in the two countries. Under free trade, country 1 specializes in industries where teams are larger and country 2 in those where they are smaller. As a result, average team size increases in the former country and decreases in the latter.

6 Application: Measuring Institutional Quality

The main qualitative insight of our theory can be summarized as follows. Countries with better institutions and/or more human capital per worker shall produce and export relatively more in the more complex industries. In this section, we use this insight to identify in the data which countries have—according to our theory—better institutions. Our empirical strategy is simple. First, we identify which countries export relatively more in the more complex industries. Second, we ask how much of the previous cross-country variation is predicted by differences in human capital alone. Whatever is left unexplained, we then interpret as the result of differences in institutional quality.

6.1 Data

Complexity. In our model, complexity, z^i , measures the magnitude of fixed training costs in industry i . To estimate these costs, we use the PSID surveys of 1985 and 1993 which ask workers of different industries: “Suppose someone had the experience and education needed to start working at a job like yours. From that point, how long would it take them to become fully trained and qualified (to do a job like yours)?” Our proxy for complexity is equal to the average number of months necessary to be fully trained and qualified in industry i .¹⁴ It ranges from 2.38 months—“knitting mills”—to 35.19 months—“optical and health

¹⁴In our model, the average training costs per worker $\frac{z}{N_z}$ is an increasing function of the total training costs z ; see equation (8). Hence, the average number of months necessary to be fully trained and qualified in a given sector is a valid proxy for complexity (in spite of the obvious fact that this number also depends on the extent of the division of labor).

services supplies”; see Table B1.

Human Capital per Worker. In order to measure human capital per worker in country c , h_c , we use the estimates of HALL and JONES [1999], which are based on the average educational attainment in 1985 reported in BARRO and LEE [2000]. Country characteristics for all exporters in the sample are given in Table B2.

Trade Flows. We use trade data from the 1992 World Trade Flows Database; see FEENSTRA et al. [2005]. Our final sample includes 20 industries, which together account for 57% of world exports in manufacturing; see Appendix B for details. In order to limit the prevalence of zero imports—a standard issue in the gravity literature; see e.g. HANSON and XIANG [2004]—we limit our sample to the 21 largest exporting countries and the 34 largest importing countries. Together, these countries account for 90% of world exports and imports in the sample, respectively. After dropping all observations that contain zero trade values (25% of all observations), we end up with a total of 10,756 observations.

6.2 Comparative Advantage: Pins or Computers?

In order to identify the pattern of comparative advantage across countries and industries, we follow COSTINOT and KOMUNJER [2006] and consider the following linear regression¹⁵

$$\ln x_{cd}^i = \alpha_{cd} + \beta_d^i + \gamma_c z^i + \varepsilon_{cd}^i \quad (15)$$

where x_{cd}^i are the exports from country c to a destination d in industry i ; α_{cd} is an exporter-importer fixed effect which aims to capture the impact of wages in country c as well as trade barriers between countries c and d (e.g. physical distance, existence of colonial ties, use of a common language, or participation in a monetary union); β_d^i is an importer-industry fixed effect which aims to capture the variation in policy barriers and preferences across importing countries d and industries i ; and ε_{cd}^i is an error term which is assumed to be independent across countries c and d and industries i .

According to Equation (15), the pattern of comparative advantage is entirely determined by the exporter fixed effect, γ_c . To see this, consider 2 exporters, c_1 and c_2 , such that $\gamma_{c_1} > \gamma_{c_2}$; and 2 industries, i_1 and i_2 ,

¹⁵COSTINOT [2005] shows how the model developed in Section 3 can be generalized to lead to Equation (15). The key ingredient of the generalized model is the existence of random productivity shocks a la EATON and KORTUM [2002] within each industry.

Table 1: Revealed Comparative Advantage in the more Complex Industries

Country	Ranking
Japan	1
United States	2
Sweden	3
Switzerland	4
Canada	5
Singapore	6
United Kingdom	7
Germany	8
Netherlands	9
France	10
Austria	11
Belgium	12
Taiwan	13
Spain	14
Italy	15
Mexico	16
Malaysia	17
Thailand	18
Hong Kong	19
South Korea	20
China	21

such that $z^{i_1} > z^{i_2}$. Taking the differences-in-differences in Equation (15) we get

$$E \left[\ln \left(x_{c_1d}^{i_1} / x_{c_1d}^{i_2} \right) - \ln \left(x_{c_2d}^{i_1} / x_{c_2d}^{i_2} \right) \right] = (\gamma_{c_1} - \gamma_{c_2}) \cdot (z^{i_1} - z^{i_2}) > 0$$

In other words, the country with a higher γ_c tends to export relatively more (towards any importing country) in the more complex industries.

The ranking of the OLS estimates of γ_c is reported in Table 1, from the highest to the lowest value. According to this ranking, Japan has a comparative advantage in the more complex industries relative to any other country in the sample. Conversely, China has a comparative disadvantage in the more complex industries relative to all other countries.

6.3 Which Countries Have Good Institutions?

We now investigate how much of the previous cross-country variation can be explained by differences in human capital alone. Formally, we consider the following linear regression

$$\hat{\gamma}_c = \alpha + \beta h_c + \varepsilon_c$$

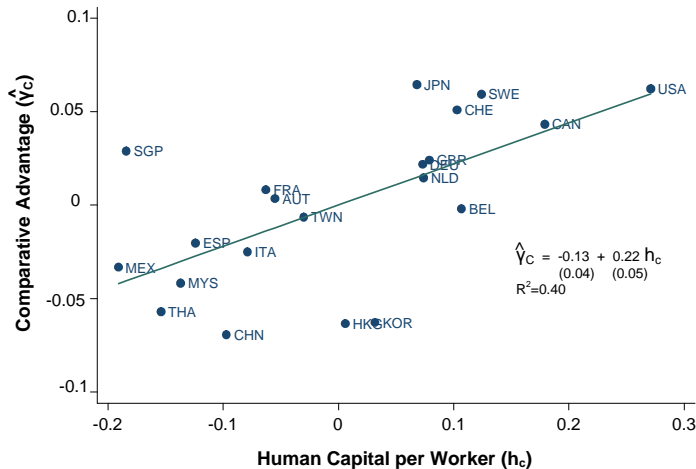


Figure 3: Comparative Advantage and Human Capital per Worker

where $\hat{\gamma}_c$ is the OLS estimate of γ_c ; and ε_c is an error term which is assumed to be independent across countries.

Our results are presented in Figure 3. In line with our theory, we find that countries with higher levels of human capital tend to export relatively more in the more complex industries. The OLS estimate of β is positive and statistically significant. A substantial amount of cross-country variation, however, remains unexplained: the R^2 of the previous regression is equal to 0.40.

We use this unexplained component of the pattern of comparative advantage as a measuring tool for the quality of institutions. Formally, we compute our revealed measure of institutional quality as

$$\hat{\theta}_c \equiv \hat{\gamma}_c - \hat{\beta}h_c$$

where $\hat{\beta} = 0.22$ is the OLS estimate of β . If a country exports more in the more complex industries than its level of human capital predicts, we infer that—in accordance with our main qualitative insight—it has good institutions. Graphically, countries with good institutions are those above the regression line in Figure 3. The further away from the regression line, the better the institutions.

Table 2 presents the ranking of $\hat{\theta}_c$, from the highest to the lowest value. According to our estimates, the top-3 countries in terms of institutional quality are Singapore, Japan, and Sweden, whereas the bottom-3 are China, Hong-Kong, and South Korea. The United States are in

Table 2: Revealed Institutional Quality

Country	Ranking
Singapore	1
Japan	2
Sweden	3
Switzerland	4
France	5
Austria	6
Mexico	7
Spain	8
United Kingdom	9
Germany	10
Canada	11
United States	12
Taiwan	13
Netherlands	14
Italy	15
Malaysia	16
Thailand	17
Belgium	18
China	19
Hong Kong	20
South Korea	21

the middle of the pack. Although the United States have a strong comparative advantage in the more complex industries, they also have very high levels of human capital.

To conclude, we investigate how our revealed measure of institutional quality relates to two existing proxies. The first one, “Rule of Law”, has been developed by KAUFMANN et al. [2005] and used by LEVCHENKO [2004] and NUNN [2005]. This proxy “includes several indicators which measure the extent to which agents have confidence in and abide by the rules of society. These include perceptions of the incidence of crime, the effectiveness and predictability of the judiciary, and the enforceability of contracts”. The second one, “Ability to Perform”, is based on the quality of the workforce index developed by Business Environment Risk Intelligence (B.E.R.I) S.A.. It measures “the attributes of the workforce that contribute to its ability to perform” including: work ethic; availability and quality of trained manpower; class, ethnic and religious factors; attention span and health; and absenteeism”.¹⁶

¹⁶See <http://www.beri.com/qwiExplanation.asp> for details. “Ability to perform” corresponds to B.E.R.I.’s subindex “Workforce Characteristics” in 1995.

Table 3: Covariance Matrix

	Revealed Institutional Quality	Rule of Law	Ability to Perform
Revealed Institutional Quality	1.00		
Rule of Law	0.74	1.00	
Ability to Perform	0.56	0.70	1.00

The covariance matrix between our revealed measure of institutional quality and the two previous proxies is given in Table 3. All three variables are positively correlated. This suggests that better institutions—when measured by “Rule of Law” or “Ability to Perform”—do confer a comparative advantage in the more complex industries, as emphasized in the present paper.

7 Concluding remarks

This paper proposes a simple theory of international trade with endogenous technological differences across countries. The core of our analysis lies in the extent of the division of labor or team size. According to our model, team size increases with institutional quality and complexity, but decreases with human capital per worker. Under free trade, the country where teams are larger—in efficiency units of labor—specializes in the more complex goods. In our set-up, it is the country where the product of institutional quality and workers’ human capital is larger. Hence, better institutions and higher levels of education are complementary sources of comparative advantage in the more complex industries. The previous section illustrates how these two insights can be used to identify in the data which countries have good institutions.

At a theoretical level, we have chosen to highlight the costs and benefits of the division of labor, while using a reduced-form approach to describe institutional quality. In our model, the latter is an exogenous parameter, whose value may not vary across industries. Though useful for tractability purposes, this assumption may appear unreasonably strong. For example, employers may well take the quality of their judicial system as given in practice, but try to improve the performance of their workers by offering efficiency wages. We strongly conjecture, however, that our insights regarding the pattern of trade would survive in an environment where institutional quality is chosen optimally across industries. The intuition lies in the proof of Proposition 2 and its use of the envelope theorem. As long as θ is chosen optimally in each industry, changes in z would also affect θ , but this would only be a second-order effect and the pattern of comparative advantage would

remain unchanged.¹⁷

Another limitation of our model is that workers in a given country are assumed to be identical. Although this is admittedly not the most realistic assumption, it has one important benefit. It allows us to abstract from the sorting of heterogeneous workers across industries, and in turn, to keep the Ricardian nature of our model intact. In a more general version of the model, we conjecture that workers with larger endowments would sort into more complex industries, which means that—as in GROSSMAN and MAGGI [2000], GROSSMAN [2004], and OHNSORGE and TREFLER [2004]—other moments of the distribution of human capital would affect the pattern of trade. We view the development of a model incorporating technological differences and worker heterogeneity as an ambitious avenue for future research.

¹⁷Of course, this requires that the division of labor remains less extensive in countries with worse institutions, however defined in this new environment.

8 Appendix A: Proofs

Proof of Lemma 1. We proceed by contradiction. Suppose that C^* assigns a positive mass of workers $n \in L$ to multiple jobs. Since the total number of jobs N is finite, there exists $L' \subset L$, with positive mass, such that all $n \in L'$ perform the same set of jobs $J' = \{J_{k_m}^*\}_{m=1}^M$. Let us denote L_{k_m} the total amount of labor that workers $n \in L'$ allocate to performing $J_{k_m}^* \in J'$ under C^* . Adding the workers' resource constraints, we get

$$L_{k_m} \leq \int_{n \in L'} \alpha(n, k_m) [h_c - z'] \, dn \quad (16)$$

where $\alpha(n, k_m)$ is the share of after-training labor that worker n allocates to $J_{k_m}^*$; and z' is the total number of tasks in J' . By assumption, we know that $z' > z_{k_m}^*$, the number of tasks in $J_{k_m}^*$.

Now consider a contract \tilde{C} that reallocates workers $n \in L'$ across jobs according to the following rule. For any $J_{k_m}^* \in J'$, it assigns a mass $\int_{n \in L'} \alpha(n, k_m) \, dn - \varepsilon$ of workers exclusively to $J_{k_m}^*$. The remaining $M\varepsilon > 0$ workers are not hired by the firm. It is easy to check that each group of specialists can allocate \tilde{L}_{k_m} units of labor to $J_{k_m}^*$, where \tilde{L}_{k_m} is given by

$$\tilde{L}_{k_m} = \int_{n \in M} \alpha(n, k_m) (h_c - z_k^*) \, dn - \varepsilon (h_c - z_k^*) \quad (17)$$

For ε small enough, Inequality (16), Equation (17), and $z' > z_k^*$ imply $\tilde{L}_{k_m} > L_{k_m}$. So, any potential unit that can be produced under C^* can also be produced under \tilde{C} . This means that expected output is no smaller under \tilde{C} , but that the total wage bill is smaller by $w_c M\varepsilon > 0$. A contradiction with C^* being a solution of (P). **QED.** ■

Proof of Lemma 2. Consider 2 distinct jobs J_1 and $J_2 \in J^*$. Let us denote z_1 and z_2 the number of tasks associated with J_1 and J_2 , respectively, and M_1 and M_2 the mass of workers assigned to these 2 jobs. By Lemma 1, we know that all workers specialize in 1 job. So, the total amount of labor available for performing each job is $M_1(h_c - z_1)$ and $M_2(h_c - z_2)$. Note that if the firm maximizes its profits, then all jobs must be performed on the same number of potential units, \bar{U} . (Otherwise, the firm could decrease the mass of workers performing one job, without decreasing expected output.) This implies

$$M_1 \left(\frac{h_c - z_1}{z_1} \right) = M_2 \left(\frac{h_c - z_2}{z_2} \right) = \bar{U}$$

Now consider the following minimization program

$$\min_{z_1, z_2, M_1, M_2} M_1 + M_2$$

subject to:

$$\begin{aligned} M_1(h_c - z_1) &= z_1 \bar{U} \\ M_2(h_c - z_2) &= z_2 \bar{U} \\ z_1 + z_2 &= z \end{aligned}$$

where z is the total number of tasks in $J_1 \cup J_2$. After plugging the first 2 constraints into the objective function, we get

$$\min_{z_1, z_2} \bar{U} \cdot \left(\frac{z_1}{h_c - z_1} + \frac{z_2}{h_c - z_2} \right)$$

subject to:

$$z_1 + z_2 = z$$

The two necessary first-order conditions are given by

$$\frac{\bar{U} h_c}{(h_c - z_1)^2} = \lambda \tag{18}$$

and

$$\frac{\bar{U} h_c}{(h_c - z_2)^2} = \lambda \tag{19}$$

where λ is the Lagrange multiplier associated with $z_1 + z_2 = z$. Combining Equations (18) and (19) with the constraint, we get $z_1 = z_2 = z/2$. This implies that, holding \bar{U} constant, the mass of workers necessary to perform the z tasks in $J_1 \cup J_2$ is minimized when J_1 and J_2 include the same number of tasks.

In order to conclude the proof of Lemma 2, we note that if profits are maximized, then holding the number of potential units constant, the mass of workers must be minimized. So, if J^* is a solution of (P), then for any pair of jobs $\{J_1, J_2\} \subset J^*$, J_1 and J_2 must include the same number of tasks. Since the total number of tasks that must be performed in industry i is z^i , we obtain $\int_{t \in J_k^*} dt = \frac{z^i}{N}$, for all $k = 1, \dots, N$. **QED.** ■

Proof of Proposition 2. By Equation (12), the derivative of A with respect to z^i is given by

$$\frac{dA}{dz^i} = \frac{\frac{da_2^i}{dz^i} a_1^i - a_2^i \frac{da_1^i}{dz^i}}{(a_1^i)^2}$$

Since N_1^i and N_2^i maximize expected profits, they minimize a_1^i and a_2^i , respectively. Therefore, the envelope theorem implies

$$\frac{dA}{dz} = \frac{\frac{\partial a_2^i}{\partial z^i} a_1^i - a_2^i \frac{\partial a_1^i}{\partial z^i}}{(a_1^i)^2}$$

Using Equation (9) and simple algebra, we then get

$$\frac{dA}{dz} = \mu(h_1 N_1^i - h_2 N_2^i)$$

with

$$\mu = \frac{h_2 N_2^i e^{\frac{N_2^i}{\theta_2} - \frac{N_1^i}{\theta_1}}}{h_1 N_1^i (h_2 N_2^i - z^i)^2} > 0$$

By Equation (8), $h_1 N_1^i - h_2 N_2^i > 0$ if and only if $\theta_1 h_1 > \theta_2 h_2$. **QED.** ■

9 Appendix B: Data

9.1 Complexity

In order to measure complexity, we use the questions of the PSID surveys of 1985 and 1993: “Suppose someone had the experience and education needed to start working at a job like yours. From that point, how long would it take them to become fully trained and qualified (to do a job like yours)?” The answer is expressed in number of months ranging from 1 to 97 in 1985, and 1 to 997 in 1993. Our proxy for complexity is equal to the average number of months necessary to be fully trained and qualified in a given industry. In the regressions, we normalize it to 1 in the most complex industry, “optical and health services supplies”.

Table B1: Ranking of Industries by Complexity

Industry	Complexity
Knitting mills (225)*	2.38
Miscellaneous fabricated textile products (239)*	2.55
Apparel and accessories (231-238)*	5.20
Yarn, thread, and fabric mills (221-224, 228)*	5.28
Footwear, except rubber (313, 314)	5.52
Logging (241)	7.52
Bakery products (205)	8.21
Rubber products (301-303, 306)*	9.32
Canning and preserving fruits, vegetables, and seafoods (203)	9.51
Meat products (201)	9.75
Furniture and fixtures (25)*	10.94
Sawmills, planing mills, and mill work (242, 243)	12.19
Miscellaneous paper and pulp products (264)	12.36
Miscellaneous food preparation and kindred products (206, 209)	12.43
Miscellaneous plastic products (307)	13.50
Cement, concrete, gypsum, and plaster products (324,327)	13.56
Paperboard containers and boxes (265)	13.60
Motor vehicles and motor vehicle equipment (371)*	14.01
Miscellaneous fabricated metal products (341, 343, 347, 348, 349)*	14.70
Electrical machinery, equipment, and supplies, not elsewhere classified (361, 362, 364, 367, 369)*	15.84
Household appliances (363)*	16.00
Fabricated structural metal products (344)*	16.90
Glass and glass products (321-323)*	17.36
Miscellaneous wood products (244, 249)	17.70
Pulp, paper, and paperboard mills (261-263, 266)	17.86
Miscellaneous manufacturing industries (39)*	19.96
Newspaper publishing and printing (271)	20.35
Radio, T.V., and communication equipment (365, 366)	21.04
Machinery, except electrical, not elsewhere classified (355, 356, 358, 359)*	21.43
Blast furnaces, steel works, rolling and finishing mills (3312, 3313)	21.87
Beverage industries (208)	22.00
Printing, publishing, and allied industries, except newspapers (272-279)	22.28
Ship and boat building and repairing (373)*	24.61
Metalworking machinery (354)*	26.66
Industrial chemicals (281)	26.92
Electronic computing equipment (3573)*	29.37
Construction and material handling machines (353)*	29.88
Drugs and medicines (283)	31.00
Aircraft and parts (372)*	31.84
Optical and health services supplies (383, 384, 385)*	35.19

Together, these surveys provide us with a total of 3341 observations, covering 82 manufacturing industries. The industry classification is developed within the 3-digit Standard Industrial Classification (SIC) from 1972; the SIC codes are indicated in parentheses. Table A1 reports the ranking of the 40 industries for which we have more than 25 observations.

9.2 Exporter characteristics

In order to facilitate comparisons, all country characteristics are expressed as ratios to US values.

Table B2: List of Exporters

Country	Human Capital per Worker	Rule of Law	Ability to Perform
Austria	0.67	1.11	1.12
Belgium	0.84	0.92	1.16
Canada	0.91	1.04	0.97
China	0.63	-0.25	0.60
France	0.67	0.92	1.12
Germany	0.80	1.06	1.21
Hong-Kong	0.74	0.96	1.28
Italy	0.65	0.50	1.03
Japan	0.80	0.89	1.45
Malaysia	0.59	0.47	0.78
Mexico	0.54	-0.07	0.84
Netherlands	0.80	1.08	1.28
Singapore	0.55	1.19	1.42
South Korea	0.76	0.45	1.19
Spain	0.61	0.69	0.92
Sweden	0.85	1.13	1.30
Switzerland	0.83	1.21	1.35
Taiwan	0.70	0.57	1.33
Thailand	0.58	0.27	0.49
United Kingdom	0.81	1.08	1.00
United States	1.00	1.00	1.00

9.3 Trade data

As mentioned in the main text, trade data are from the 1992 World Trade Flows Database; see FEENSTRA et al. [2005]. The data are organized by the 4-digit Standard International Trade Classification (SITC), revision 2. In order to compute the bilateral exports for every sector present in Table B1, we proceed as follows. First, we compute the set of 4-digit SIC 1972 codes associated with each sector, and then convert these codes into the 4-digit SITC, revision 2. We drop all SITC sec-

tors associated with more than one index of complexity. The bilateral exports in a given sector are equal to the sum of the exports over the remaining SITC sectors. We obtain a sample of 20 industries, denoted with asterisks in Table B1, which together account for 57% of world exports in manufacturing in 1992.

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