

# A Team-Production Approach to Wages, Employment and Trade

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Boston College

The Graduate School of Arts and Sciences

Department of Economics

A TEAM-PRODUCTION APPROACH TO WAGES, EMPLOYMENT  
AND TRADE

a dissertation

by

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by

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Abstract

This dissertation contains three chapters, each investigating different topics on wages, employment and trade, based on a common team-production approach with the fundamental assumption that in real economy production is organized in teams of agents, each specializing in different tasks.

In the first chapter, I present a model that incorporates multidimensional skill endowment for each agent and team production where team members completely specialize in different tasks into the standard Heckscher-Ohlin framework, and investigates the effects of skill distributions on trade and wages. The equilibrium is characterized by the

“effective endowment”, the part of endowment that is actually utilized in production, which depends on the team matches and the task specialization within matched teams. The paper shows that: (1) the endowment correlation between skill dimensions for each agent and the skill dispersion across agents, additional to aggregate endowment, both matter for the pattern of specialization; (2) the different endowment distributions also generate different wage inequality across countries; a common job polarization pattern is generated in all developed economies in the globalization era; (3) there are new gains from trade, attributed to potential adjustments of the effective endowment after integration. It provides a unifying framework to explain both the trade patterns and labor market outcomes between similar countries. It also reveals a new channel through which institutions may have effects on comparative advantage and trade. In particular, the effects of different educational policies and labor market institutions on trade through shaping the skill distributions in each country are highlighted. Moreover, by linking globalization to the labor market, it provides an alternative explanation for some stylized facts on wage inequality and employment changes.

In the second chapter, I propose a framework based on the team-production approach to deal with asymmetric information. Information asymmetry may cause market failure. With multiple dimensions of private information and proper market segmentation, this problem may be mitigated or even solved. In a labor market example, there are heterogeneous types of managers and workers. Production is performed by

manager-worker pairs. There exist multiple industries with production functions that differ in their intensities of manager/worker tasks. When managers' type and workers' type are both private information, those good managers (workers) choose to locate in industries with higher manager (worker) intensities given the bargaining power between managers and workers. Due to the market segmentation by different industries, each manager (worker) faces a trade-off between a higher pay-off to her own type in a manager-intensive (worker-intensive) industry, and a better partner in a less manager-intensive (worker-intensive) industry. In equilibrium, heterogeneous managers (workers) are endogenously sorted by their types into different industries. Thus information asymmetry is mitigated in the segmented markets. Efficiency may be obtained even with information asymmetry.

The third chapter introduces a team-production approach built on a two-sided search problem with task-specific human capital to investigate the specificity and return of human capital. With increasing worker mobility in the labor market, it is important to identify the boundary and return of human capital. Empirical evidences on the specificity of human capital are mixed. There are two categories of heterogeneous agents in the market searching for a partner of a different category in order to form a team and produce. A stable match is formed only when both sides agree. With search frictions, the search equilibrium is characterized by clusters of agents. This approach generates a form of firm-specificity of human capital, which explains the firm-sponsored general-skill

training. An empirically found negative correlation between the wage levels and turnover rates also arises from the model. Additionally, this model provides a new micro-foundation for the social increasing returns in human capital accumulation. Several interesting empirical implications from this approach are also discussed.

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This thesis is dedicated to my parents, my brother and sister, brother in law and sister in law, my lovely nephew and niece.

*Lux et Veritas*, for those who I love!

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# 1. EFFECTIVE ENDOWMENT, TRADE AND WAGES

## 1.1 Introduction

During the era of globalization, the United States (US) and (continental) Europe have experienced different trade patterns despite similar aggregate endowment. In general, it seems that the European countries export relatively more manufacturing goods, cars and equipments for instance, while the US mainly exports services such as software and consulting.<sup>1</sup> The labor market outcomes in these two regions also differ.<sup>2</sup> It is well known that the wage inequality is higher in the US than in Europe. Recent literature finds a common “job polarization” pattern of employment change in both regions, accompanying the divergent wage evolutions.<sup>3</sup>

The current literature still lacks a unified framework to explain both the behavior of trade and labor markets in these two regions in the globalized economy.<sup>4</sup> This paper fills this gap by building a model that can explain both the patterns of trade and the labor market outcomes in the US and Europe, based on the observation that the distributions of skills across the labor forces of the two regions differ.<sup>5</sup>

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<sup>1</sup> This is true especially for Germany. The share of service in total export also decreases for France and Italy relative to the US during this period. Data source: World Bank and OECD national accounts data.

<sup>2</sup> See Freeman and Katz (1995) among others for reviews of these differences. This paper does not explain all these differences. Instead, it focuses on explaining the trade patterns and the coexistence of a job polarization in both the US and Europe with divergent wage evolutions across the two regions.

<sup>3</sup> Job polarization is a pattern of employment change in which the top-wage jobs and bottom-wage jobs experience a higher increase than the middle-wage jobs. See Autor, Katz and Kearney (2006, 2008), Goos and Manning (2007) and Goos, Manning and Salomons (2009) for detail. It is also known as the “shrinking middle class” phenomenon in the news and media.

<sup>4</sup> Within the trade literature, the effect of trade integration on inequality is inconclusive; see Goldberg and Pavcnik (2007) and Harrison, McLaren and McMillan (2011) for reviews of related works. In the labor literature, the effect of trade and off-shoring on labor outcomes is usually considered quantitatively small. Particularly, when explaining the job polarization with the task approach, Autor et al (2006, 2008) argues that the off-shoring ability of different tasks only has a quantitatively small effect.

<sup>5</sup> See Grossman and Maggi (2000), Bombardini et al (2012), and Ohnsorge and Trefler (2007) for evidences on the differences of talent distributions across countries.

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The model deviates from the standard Heckscher-Ohlin framework by assuming a multidimensional skill endowment for each agent and team production in which team members completely specialize in different tasks.<sup>6</sup> In the optimal labor allocation, agent matches and task assignments within each match are chosen to maximize the total output. As a result, the equilibrium is characterized by the “effective endowment”, the part of endowment that is actually utilized in production, instead of the initial skill endowments. Under these settings, it is then shown that both the endowment correlation between skill dimensions and the skill dispersion across agents matter for the pattern of specialization and wages, complementing the standard channel in which relative aggregate factor endowments shape the comparative advantage.

Upon integration, there is a new source of gains from trade in this model. These new gains are attributed to potential adjustments of the effective endowment through reshuffling the production teams or reassigning tasks within teams. Traditional gains from trade originate from the relative price changes and the reallocation of resources into industries where one has comparative advantages. This model does not take current utilized resources, the effective endowment, as given. Instead, it further allows the economy to adjust its utilized resources in production so as to achieve better outcome from its initial endowment after integration.

When applied to analyse the labor markets in the US and Europe, this model links globalization with the wages and employment changes. It provides an alternative explanation for the job polarization pattern found in both regions along with different wage evolutions. More generally, this model generates a universal job polarization in all the North economies when they open to trade with the South in the global economy. Meanwhile, divergent wage evolutions across North countries result from their different comparative advantages and specialization patterns among themselves, attributed to their different endowment correlations and skill dispersions.

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<sup>6</sup> Ohnsorge and Treffer (2007) considers multidimensional endowment in an open economy without team production. The team organization of production shares features with Milgrom and Roberts (1990), Kremer (1993) and Grossman and Maggi (2000).

To see the intuition behind these results, we first start with the endowments. The initial skill endowments of agents are shaped by the educational systems, which are exogenously given in each country.<sup>7</sup> Think of agents' skills in two dimensions: the entrepreneur's managerial ability and the worker's production skill.<sup>8</sup> Correspondingly, output production requires a manager task and a worker task to be performed, with different task intensities in different industries. In the competitive environment, each agent on the team will get his share of contribution to the final output, which is equal to the intensity of the task that he performs. Obviously, those industries with extreme-value intensities have higher wage inequality.

In an educational system where general-skill training is emphasized, in the US for example, there is a high correlation between the two dimensions in each agent's skill endowment.<sup>9</sup> On the other hand, in an educational system where skill-specific vocational training is emphasized, in continental Europe for instance, the correlation between the two skill dimensions in each agent's endowment is low. Assuming similar aggregate educational resources (aggregate skill endowment) along each dimension in these two regions, their endowment distributions still differ in their endowment correlations due to different educational policies.<sup>10</sup> When production is organized in teams, the high-correlation US ends up with more teams with extreme-value effective skill-ratios in production.<sup>11</sup> These teams have the comparative advantage in those industries with extreme-value task intensities.<sup>12</sup> In the competitive environment this results in higher wage inequality in the US than in Europe.<sup>13</sup>

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<sup>7</sup> I will defend this assumption by arguing that the effect of changes in the educational system on skill endowments takes a long period of time to be realized. Thus skill endowment seems more like an exogenous variable than others in this model, such as the globalization/integration.

<sup>8</sup> While one can think of other kinds of skill dimensions, it is not crucial what and how many the skill dimensions are. The key is that with completely specialized agents in team production, individuals face a trade-off between their skill attributes.

<sup>9</sup> A high correlation between two endowment attributes for agents means that if he/she is a good manager, he/she has a high probability to be also a good worker.

<sup>10</sup> See Krueger and Kumar (2004a) for a comparison of educational systems in the US and European countries. See Ohnsorge and Treffer (2007) for evidences on skill correlation differences.

<sup>11</sup> Effective skill-ratio is the ratio of the two utilized skills from the team-members.

<sup>12</sup> See Ohnsorge and Treffer (2007) for more on the comparative advantage for endowment bundles with different skill-ratios. In general, the intuition is that teams choose the optimal industry according to their (effective) skill ratios, to maximize the output of the whole (effective) bundle.

<sup>13</sup> This result is also shown under non-competitive environment in the text.

In reality, service industries are usually those where some star member's exceptional work largely determines the output, while other supporting members only contribute a small share. For example, in the software industry, the manager is in charge of problem-solving task, while the worker is just typing and copying the codes. The value is mainly attributed to the manager's performance. Hence he will get a very large share of the final output. On the other hand, manufacturing industries usually needs both tasks to be performed with similar intensity. For example, when producing a car, it is very important for the managers to know how to organize the production; it is also important for workers to do a good job in actually producing the car. In the end, higher endowment correlation results in comparative advantage for the US in those extreme-intensity service industries and higher wage inequality level; the opposite is true for the Europe. Moreover, when two countries have the same aggregate skill endowment along each dimension and the same correlation, a higher skill dispersion along one or more dimensions also generates more teams with extreme-value effective skill-ratios in production. Thus a higher dispersion amplifies the effect of a higher correlation on the comparative advantage and wage inequality.<sup>14</sup>

In the case of North-South trade, assuming that South countries have caught up with the North in their worker training but not in their entrepreneur training, the relative endowment of entrepreneurial ability is lower in the South.<sup>15</sup> The existing industries in the North are biased in their task intensities such that the managerial task is more important and intensively used in all industries.<sup>16</sup> Thus before globalization, the North economies have their top-wage jobs and bottom-wage jobs in those service industries with very high managerial task intensity and very low worker-task intensity. After integration with the South, the North economies have comparative advantage in these service industries. Hence there are more teams with extreme skill-ratios formed and entering the service industries.

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<sup>14</sup> Indeed, the dispersion (or diversity) of human capital/skill distribution is found to be higher in the US than those continental European countries. See Grossman and Maggi(2000), Bombardini et al (2012) for some primary evidence.

<sup>15</sup> This is likely true due to the lack of entrepreneurial culture, lower financial development or poor institutions in developing countries.

<sup>16</sup> Given the industry structure in the North, with very small share of agriculture, I argue that this assumption is reasonable.

As a result, there are higher increases in employment for those top-wage and bottom-wage jobs relative to those middle-wage jobs in the North. Thus this model can generate an universal pattern of job polarization in all the North countries as empirically found.<sup>17</sup>

As contributions to the trade and labor literature, this paper points out the effect of educational policies on the comparative advantage by showing that the higher moments of endowment distributions shaped by a country's educational system are crucial in trade; By providing an alternative explanation for the job polarization from an open economy perspective, it also indicates a potential role for globalization behind those labor market phenomenons. Hence the interdependence between trade and labor market is also highlighted. In particular, this paper is closely related to several strands of literature as follows.

First, this paper extends the standard channel in which relative factor endowments shape the pattern of trade by showing that higher moments of the endowment distribution also matter. Grossman and Maggi (2000) (henceforth GM) first put forward the idea that a relatively diverse skill distribution generates comparative advantage in industries with sub-modular technologies. Bombardini et al (2012) find empirical support for GM's idea. Ohnsorge and Trefler (2007) (henceforth OT) further develop this idea in an open economy model with multidimensional skill endowment. This paper shares a lot of implications with OT. The difference is the team production assumption, which allows me to draw new implications on the job polarization and wage inequality in the US and Europe.<sup>18</sup>

Second, this paper complements those works on the gains from trade by identifying a new source of gains from trade. These new gains come from the adjustments of the effective endowment upon integration.<sup>19</sup> There is a large number of papers along this line, see Broda and Weinstein (2006), Feenstra (2004) for example. Moreover, this model may exhibit gains

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<sup>17</sup> When combined with the trade between North economies, this model predicts that the job polarization pattern is more significant in the US than in Europe. Current literature still lacks rigorous investigation on this comparison. However, the data and figures from Autor et al (2006) and Goos and Manning (2007) seems to indicate that the extent of job polarization is indeed greater in the US than in Europe.

<sup>18</sup> See also Bougheas and Riezman (2007) and Sly (2012) for more about the effect of endowment distributions on trade patterns.

<sup>19</sup> There are also papers emphasizing the change of utilized endowment after trade liberalization, due to the increased market competition for example. The under-utilization of initial endowment results from various distortions. However, in my model, the autarky utilization of endowment is the optimal choice. Thus the new gains from trade in this model exist even when the market is complete.

similar with those in the scale economies in certain circumstances.

Third, this paper also extends the Roy model by showing that different endowment structures, higher correlation and dispersion in the US than in Europe, contribute to the inequality differences. The trade between these two regions amplifies this difference. Gould (2002) finds that the inequality increase in the US is increasingly characterized by the absolute advantage effect, indicating a decrease of the comparative advantage effect. Blum (2008) finds that the increasing share of the service sector in the US explains almost 60% of the relative increase in wages of skilled workers between 1970 and 1996. On the other hand, this paper also indicates a role for globalization behind the job polarization pattern, complementing the existing explanations proposed by Autor et al. (2006, 2008), Autor and Dorn (2012) among others.<sup>20</sup>

Fourth, this paper shares some implications with several other papers. Eeckhout and Jovanovic (2012) show that there are more managers in the developed countries, which is a natural result of this model when task off-shoring is allowed. Krueger and Kumar (2004a, 2004b) also highlight the effect of educational policies. Instead of focusing on the effects on technology adoption, hence growth rate, I focus on their comparative static effects on the pattern of specialization and wages. From a development point of view, this paper also shares with Buera and Kaboski (forthcoming) and Kaboski (2009) in explaining the increasing skill premium (or wage inequality) in the US with the structural changes towards service industries.

The next section presents a baseline model, illustrating the basic structure and main intuitions. The general model with continuous endowment levels and a continuum of industries is laid out in section 3. The generalized trade theories, the new gains from trade and the implications on wage inequality and job polarization are presented after the general model. Section 3 ends with some other model applications and discussions. Section 4 concludes.

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<sup>20</sup> For other explanations for job polarization, see Costinot and Vogel (2010), Monte (2011); For more on the interdependence between trade and labor market, see Davidson and Sly (2012) for an example. The importance of team production organization is also highlighted there.

## 1.2 *The Baseline Model*

### 1.2.1 *Setup*

#### *Endowment*

In the baseline model I consider the two-dimensional talents endowment, think of them as the entrepreneurial ability and worker skills:  $(E, W)$ . Accordingly in production there are two tasks corresponding to each talent dimension.

In order to show the main intuitions in a simple way, without loss of generality, I assume that there are finite types of agents. Particularly, I assume two talent levels along each talent dimension:  $\{H, L\}$ . Thus there are high-skill or low-skill entrepreneurs and high-skill or low-skill workers.

Then the possible values for each agent's talent endowment bundle  $(E, W)$  in this North economy are the following:

$$(E, W) = \{(L, L), (H, H), (L, H), (H, L)\}$$

Agents with endowment bundle  $(L, L)$  have low level of entrepreneurial ability and also low level of worker skill; Agents with bundle  $(H, H)$  are the most educated, they have both high level of entrepreneurial ability and also high level of worker skill; Agents with endowment  $(H, L)$  has good entrepreneurial training but poor worker skill training; Agents with endowment  $(L, H)$  have good training in worker skill but little in entrepreneurial activities.

Notice that the correlation of talent endowment along two dimensions for individual agent,  $E$  and  $W$ , is one for the first two pairs of values, no matter how many there are each of them. And the correlation is negative one for the last two pairs. In general, the correlation can vary between these two extreme values. In the real world, endowment correlations between two dimensions for individual agent do differ across countries, due to different education systems.<sup>21</sup>

<sup>21</sup> The empirical evidence for different skill endowment correlations across countries is limited in the current

To simplify the analysis, I define two types of North economies. The type-I North economy has talent endowment bundles consisting of the first two pairs of values listed above, with a perfect positive correlation between two dimensions of individual agent's endowment:

$$(E, W) = \{(L, L), (H, H)\};$$

The type-II North economy has endowment bundles taking values of the last two pairs, with a perfect negative correlation across dimensions:

$$(E, W) = \{(L, H), (H, L)\}.$$

All other North economies with different endowment correlations can be generated by a linear combination of these two types of economies.<sup>22</sup>

When considering the case of North-South trade, I need to assume talent endowments for the South economy. A consensus seems to be that the South has caught up fast along the worker skills dimension over the past decades, while remaining relatively poor in entrepreneurial capability either because of the biased education system, poor institutions, low level of financial development or lack of entrepreneurial culture.<sup>23</sup> Thus the South has a similar level of  $W$  talent endowment as the North, but a relatively lower level of  $E$  talent endowment. For simplicity, I assume that the South has the same level of talent endowment as the North along the  $W$  dimension, and a lower level along the  $E$  dimension. The potential values of talent endowment bundles  $(E, W)$  for the agents in the South are then:

$$(E, W) = \{(L', L), (H', H), (L', H), (H', L)\}$$

---

literature. See Ohnsorge and Treffer (2007), Krueger and Kumar (2004a) among others for preliminary evidences for the US and Europe.

<sup>22</sup> Since there are four possible values of endowment bundle, which are all included in these two type of North economies. Endowment of any economy can be divided into two large groups, one containing  $(L, L), (H, H)$  bundles, the other containing all  $(L, H), (H, L)$  bundles. The first group is a linear combination of the type-I economies and the second is a type-II North economy combination.

<sup>23</sup> There are many empirical papers documenting the catch-up in manufacturing in the developing economies. In the contrast in the service sector, where there are more small business and entrepreneurial talent is more intensively used, there is no catch-up in labor productivity. See Duarte and Restuccia (2010) among others.

where  $H' = \theta H$  and  $L' = \theta L$ ,  $\theta < 1$ . Two types of South economies with perfect positive and negative endowment correlations are then defined similarly as in the North.

### *Production*

The technologies of production are the same in the North and South. There are two industries, service ( $S$ ) and manufacturing ( $M$ ), with a Cobb-Douglas production functions. I assume that in all industries talent  $E$  is always more intensively used than the  $W$  talent.<sup>24</sup> Moreover, in the service industry, entrepreneur's personal success is even more important. Think of the software service for example, the manager on the team performs a problem-solving task and the worker is writing and copying the codes. The output of this team largely depends on how many problems that this manager is able to solve, the worker's contribution is only minor. Think of another manufacturing industry, automobile production, it is important for the manager to know how to organize the production process, and also very important for the worker to do a good job in actually producing the car. Thus the entrepreneurial talent is more intensively used in the service industry than in the manufacturing. The two production functions for these two industries are given by the following:

$$S = E^\alpha W^{1-\alpha}, \quad M = E^\beta W^{1-\beta}, \quad \alpha > \beta \geq 1/2; \quad (1.2.1)$$

where  $\alpha$  and  $\beta$  are the entrepreneurial ability ( $E$ ) intensities in service and manufacturing industry respectively.

### *Preference*

Agents' welfare comes from goods consumption. Each agent's utility from consuming two goods is given by:

$$U = C_s^\mu C_m^{1-\mu}; \quad (1.2.2)$$

---

<sup>24</sup> In the real economy, this seems to be a reasonable assumption, given the extremely higher pay to those managerial jobs. The model does not need this assumption to generate implications on comparative advantage and gains from trade, or wage inequality; It only needs a moderate form of this assumption to generate job polarization. Detail on this will be presented in section 4.

where  $C_s$  is the consumption of service good and  $C_m$  is the consumption of manufacturing good.

### 1.2.2 *Random Matching*

The agent matching process can be modeled in many ways. The most common candidates are the random matching process and the social planner's optimal matching arrangement. I analyze different trade patterns with the random matching in this subsection and under optimal matching in the next.

In the random matching case, agents meet with each other in a random fashion and form teams after each meeting. Then each team chooses its task assignment, i.e. who will be the entrepreneur and who will be the worker, and at the meantime which industry to enter.

### *North-North Trade*

To analyze the role of multidimensional endowment in trade, I first consider two North economies with the same aggregate talent endowments along both  $E$  and  $W$  dimensions. The only difference is the correlation between the two dimensions within each endowment bundle. Particularly, in a Type-I North economy with a perfect positive correlation, its endowment bundles are:

$$(E, W) = \begin{cases} (L, L) & \text{with measure } 1 \\ (H, H) & \text{with measure } 1 \end{cases}$$

And in a Type-II North economy with a perfect negative correlation, its talent endowments are:

$$(E, W) = \begin{cases} (L, H) & \text{with measure } 1 \\ (H, L) & \text{with measure } 1 \end{cases}$$

As we can see, the value of agent measures are chosen in a way to ensure that the aggregate endowments along each dimension are the same for these two economies.

Under the random matching process, assuming agents have incomplete information and teams are formed by randomly matching two agents, in the Type-I North economy the matching outcome are the following, I use the  $\otimes$  to denote matched agents:

$$(E, W) \otimes (E, W) = \begin{cases} (L, L) \otimes (L, L) & \text{with measure } 0.25 \\ (L, L) \otimes (H, H) & \text{with measure } 0.5 \\ (H, H) \otimes (H, H) & \text{with measure } 0.25 \end{cases}$$

After matching, each matched pair of agents have to assign the two tasks among themselves and also choose the industry ( $S$  or  $M$ ) they are going to enter based on their talent endowment bundles, given the good prices and production functions. For the above matches, the effective talent bundles chosen by all matched teams in this type-I North economy will be:

$$(E, W) = \begin{cases} (L, L) & \text{with measure } 0.25 \\ (H, L) & \text{with measure } 0.5 \\ (H, H) & \text{with measure } 0.25 \end{cases}$$

Teams with agents' endowment bundles  $(L, L) \otimes (H, H)$  will allocate the entrepreneurial task to the  $(H, H)$  guy and the worker task to the  $(L, L)$  agent due to the simplifying assumption that the  $E$  intensities  $\alpha$  and  $\beta$  for two industries are both greater than  $1/2$ .

Analogously, in the Type-II North economy the random matching outcome are the following:

$$(E, W) \otimes (E, W) = \begin{cases} (L, H) \otimes (L, H) & \text{with measure } 0.25 \\ (L, H) \otimes (H, L) & \text{with measure } 0.5 \\ (H, L) \otimes (H, L) & \text{with measure } 0.25 \end{cases}$$

And the effective talent bundles of for these matched teams in this type-II North economy

will be:

$$(E, W) = \begin{cases} (L, H) & \text{with measure } 0.25 \\ (H, H) & \text{with measure } 0.5 \\ (H, L) & \text{with measure } 0.25 \end{cases}$$

Notice that for these two types of North economies, for any randomly matched team, the optimal choice of effective talent bundle is unique for any good prices. It is due to the assumption on the talent intensities given the talent endowments. This assumption will be relaxed in the continuous model case.

Now I can analyze the choice of industry for each team given different good prices, together with the consumption demand for both products, I can then pin down the equilibrium prices and output quantities. Without loss of generality, I let the manufacturing good be the numeraire and then  $P_m = 1$ ,  $P_s = P$ .

In a type-I North economy, teams with effective talent bundle  $(L, L)$  or  $(H, H)$  will choose to enter the same industry for any given relative price  $P$  since they have the same effective talent ratio. In particular, when  $P = 1$  they are indifferent between producing  $S$  and  $M$ ; When  $P < 1$ , they choose to produce the  $M$  good; When  $P > 1$ , they enter the  $S$  industry. For teams with effective talent bundle  $(H, L)$ , the  $S$  industry is chosen if and only if the price  $P \geq (\frac{L}{H})^{\alpha-\beta}$  (indifferent when equality holds). Otherwise, they choose to produce the  $M$  good.

In a type-II North economy, teams with effective talent bundle  $(H, H)$  have the same supply curve as teams with the same effective bundle in the type-I North economy. So do teams with effective bundle  $(H, L)$ . For teams with effective talent bundle  $(L, H)$ , they are more likely to choose the  $M$  industry due to their high  $W/E$  ratio which gives them comparative advantage in the more  $W$ -intensive  $M$  industry. In particular, when the relative price  $P < (\frac{H}{L})^{\alpha-\beta}$ , these teams will always stay in the  $M$  industry.

The relative supply curves of two products for both types of North economies are shown in the Figure 1:

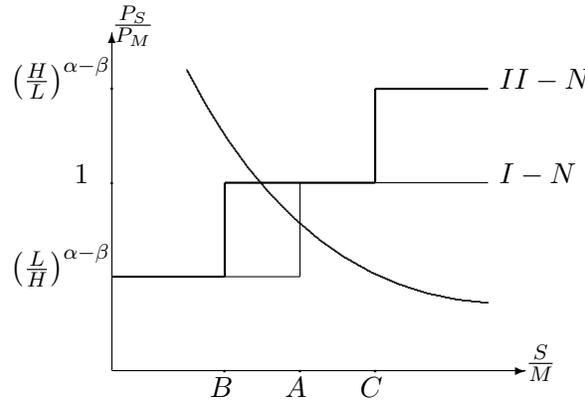


Fig. 1.1: North-North Trade

where  $A = \frac{2H^\alpha L^{1-\alpha}}{H+L}$ ,  $B = \frac{H^\alpha L^{1-\alpha}}{H^\beta L^{1-\beta} + 2H}$ , and  $C = \frac{H^\alpha L^{1-\alpha} + 2H}{H^\beta L^{1-\beta}}$ .

When these two types of North economies integrate to trade, the type-I North economy has a comparative advantage in the relatively more  $E$ -intensive industry  $S$  and the type-II North economy possesses comparative advantage in the less  $E$ -intensive industry  $M$ . The intuition behind is straightforward. The high correlation between two dimensions of talent endowment in the type-I North economy means that agent with a high level of  $E$  talent also has a high level of  $W$  talent. However, each agent can only choose one occupation and performs the corresponding task, she has to waste her other talent. Given the same level of aggregate talent endowment along each dimension in the two economies, a high correlation across two dimensions in the type-I North reduces its effective talent endowment that can be actually utilized. This further results in more teams with a high level talent along one dimension and a low level along the other in their effective talent bundles, generating its comparative advantage in industries with more extreme talent intensities.<sup>25</sup>

In contrast, in a type-II North economy with a low correlation between endowment dimensions, each agent has her own specialization along certain talent dimension. Hence when two agents with different talent endowments are matched together, they will choose their occupations, i.e. task assignment, according to their specializations. No matter which

<sup>25</sup> If there are extreme high  $W$ -intensity industries available, the type-I North will also have comparative advantage those industries.

industry they choose to enter, each choosing her relatively high level talent is always a dominant choice. In the end, the type-II North economy has more teams with similar (high) levels of talent along two dimensions in their effective bundles, generating its comparative advantages in industries with middle talent intensities.

I apply this intuition to the analysis of the specialization pattern between the US and continental Europe. Given that these two regions have similar level of aggregate educational resources to allocate to individuals, and there are multiple dimensions of skills, the resulted correlation for individual endowment between dimensions is higher in the US than that in Europe due to the general education system in US and the skill-specialized vocational education system in the Europe. This correlation difference alone generates comparative advantage for the US in those service industries with extreme intensities, and for the Europe in those manufacturing industries.

#### *North-South Trade*

In the case of North-South trade integration, I also consider two types of talent endowments for the South economies. The Type-I South economy has a perfect positive correlation between the two dimensions of talent endowments:

$$(E, W) = \begin{cases} (L', L) & \text{with measure } 1 \\ (H', H) & \text{with measure } 1 \end{cases}$$

While the Type-II South economy has a perfect negative correlation between the two talent attributes:

$$(E, W) = \begin{cases} (L', H) & \text{with measure } 1 \\ (H', L) & \text{with measure } 1 \end{cases}$$

Under random matching, in the Type-I South economy the outcomes of agent matching

are the following:

$$(E, W) \otimes (E, W) = \begin{cases} (L', L) \otimes (L', L) & \text{with measure } 0.25 \\ (L', L) \otimes (H', H) & \text{with measure } 0.5 \\ (H', H) \otimes (H', H) & \text{with measure } 0.25 \end{cases}$$

For the agent matches above, the effective talent bundles of all matched teams in this type-I South economy will be:

$$(E, W) = \begin{cases} (L', L) & \text{with measure } 0.25 \\ (H', L) & \text{with measure } 0.5 \\ (H', H) & \text{with measure } 0.25 \end{cases}$$

For the cross-matches where agents endowments are  $(L', L) \otimes (H', H)$ , as assumed  $H' = \theta H$  and  $L' = \theta L$ , the talent bundle  $(H', L)$  always outperforms the bundle  $(L', H)$  due to the simplifying assumption that in both industries the  $E$  intensities  $\alpha$  and  $\beta$  are higher than 0.5. So the effective talent bundle will always be  $(H', L)$  for these teams.

Similarly, in the Type-II South economy the possible agent matches are the following:

$$(E, W) \otimes (E, W) = \begin{cases} (L', H) \otimes (L', H) & \text{with measure } 0.25 \\ (L', H) \otimes (H', L) & \text{with measure } 0.5 \\ (H', L) \otimes (H', L) & \text{with measure } 0.25 \end{cases}$$

For the matches above, the effective talent bundles of all matched teams in this type-II South economy will be:

$$(E, W) = \begin{cases} (L', H) & \text{with measure } 0.25 \\ (H', H) & \text{with measure } 0.5 \\ (H', L) & \text{with measure } 0.25 \end{cases}$$

For those cross-matches  $(L', H) \otimes (H', L)$ , the effective bundle  $(H', H)$  is superior to  $(L', L)$  for any industry and good prices.

Since there are two types of economies both in the North and the South, there are then four different cases for North-South trade. All four possible cases are analyzed below.

**Case 1:** Type-I North with Type-I South

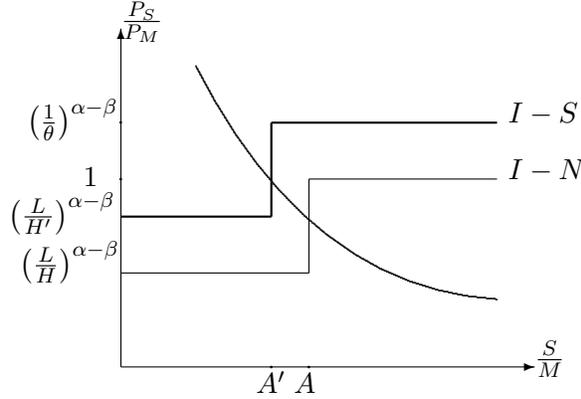


Fig. 1.2: Type-I North with Type-I South

where  $A' = A\theta^{\alpha-\beta}$ .

Since  $\theta < 1$  and  $\alpha > \beta$ , thus  $A' < A$ . And  $H' < H$ , then  $(\frac{L}{H'})^{\alpha-\beta} > (\frac{L}{H})^{\alpha-\beta}$ . As shown in Figure 2, the supply curve for the type-I South economy always locates above that for the type-I North economy without any intersection. Thus the price of  $S$  (relative to good  $M$ ) is always higher in the South economy. The type-I North economy always has comparative advantage in the relatively more  $E$ -intensive  $S$  industry. In particular, as in OT, teams choose their industry and effective talent bundle accordingly. It is those North teams with effective bundle  $(E, W) = (H, L)$  that stay in the  $E$ -intensive  $S$  industry and benefit the most from trade integration with the South.

It is useful to compare our results here with the case of a standard Heckscher-Ohlin (henceforth H-O) model. The type-I North economy has exactly the same endowment of  $W$  talent as the type-I South economy. The only difference is that South has a relatively lower endowment of  $E$  talent,  $\theta < 1$ . Endowment correlations are the same. Under the H-O framework, since the relative endowment of talent  $E$  in the type-I South economy is lower than that in the type-I North, the North economy has comparative advantage in the

$E$ -intensive industry  $S$ . As we can see, the same results of comparative advantages between the North and South are obtained in this model with multidimensional endowment.

**Case 2:** Type-I North with Type-II South

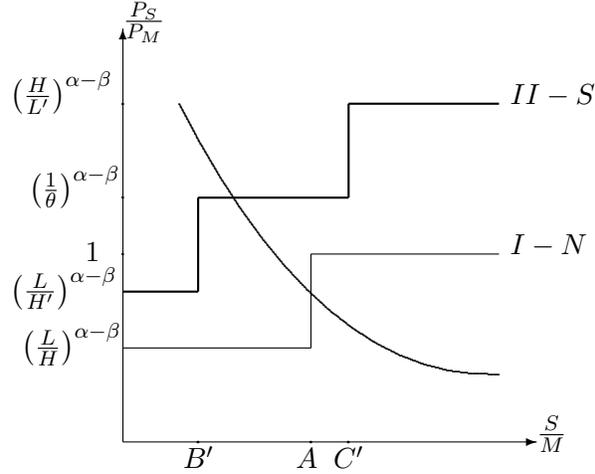


Fig. 1.3: Type-I North with Type-II South

where  $B' = B\theta^{\alpha-\beta}$ , and  $C' = C\theta^{\alpha-\beta}$ . It can be easily verified that  $B' < A < C'$  and  $(\frac{1}{\theta})^{\alpha-\beta} > 1$ .

Again, as shown in Figure 3, the supply curve for the type-II South economy always locates strictly above the one for the type-I North economy. The same comparative advantage and trade pattern will be obtained as in Case 1. In this case, the relative aggregate level of endowment is still the same as in Case 1. The North has a relatively higher endowment of talent  $E$ . In addition, the type-II South has a lower correlation of talent endowment between two dimensions. As we already know from the case of North-North trade, *ceteris paribus*, a higher correlation gives rise to comparative advantage in industries with extreme-value talent intensities. In this Case 2, the type-I North economy has a relatively higher aggregate level endowment of talent  $E$ , and also a higher correlation, both give it comparative advantage in the  $S$  industry. Thus the traditional H-O effect and the new correlation effect work in the same direction here.

**Case 3:** Type-II North with Type-I South

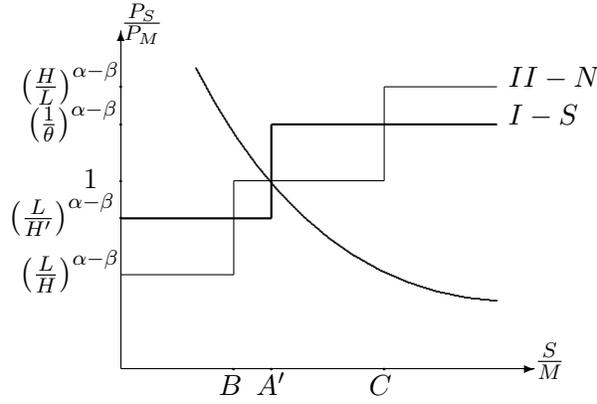


Fig. 1.4: Type-II North with Type-I South

where  $A' < C$ , the relation between  $B$  and  $A'$  is not clear, which depends on the values of  $\theta$ ,  $\alpha - \beta$ ,  $H$  and  $L$ .

As shown in Figure 4 above, now the relative location of two supply curves is not clear. The trade pattern is also indeterminate. The intuition follows from the argument I made in case 2. In the case 3 here, on one hand the type-II North economy has a relative higher level of aggregate endowment in talent  $E$ , which gives it comparative advantage in the  $S$  industry. On the other hand, the type-II North economy also has a lower correlation compared with the type-I South economy, which gives the type-II North economy comparative advantage in the  $M$  industry with modest talent intensities. These two effects counteract each other. The equilibrium trade pattern in the integrated economy depends on the net of these two effects.

In particular, when  $\theta \leq \frac{L}{H}$ , we have  $(\frac{L}{H'})^{\alpha-\beta} > 1$  and  $(\frac{1}{\theta})^{\alpha-\beta} > (\frac{H}{L})^{\alpha-\beta}$ . Then it is certain that the supply curve of the type-I South economy locates strictly above that of the type-II North economy, and the North will always have the comparative advantage in the relatively more  $E$  intensive  $S$  industry. The intuition is that, when  $\theta \leq \frac{L}{H}$ , the relative level of aggregate talent  $E$  endowment is sufficiently high in the type-II North economy, then the traditional H-O effect of relative factor endowment dominates the effect of correlation difference in shaping the comparative advantages between these two economics.

**Case 4: Type-II North with Type-II South**

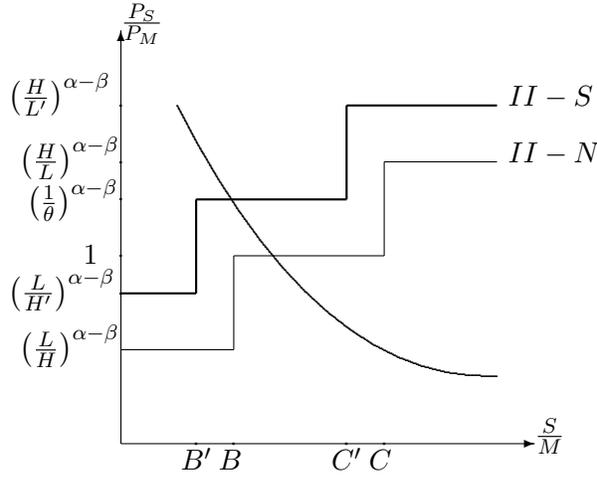


Fig. 1.5: Type-II North with Type-II South

where  $B' < B$  and  $C' < C$  always hold.

As shown in Figure 5, the supply curve for the type-II South economy always locates strictly above the one for the type-II North economy. Thus it is always the case that the type-II North economy has comparative advantage in the  $S$  industry and the type-II South economy has comparative advantage in the  $M$  industry. This case is very much similar with case 1. The correlations between two endowment dimensions in these two economies are the same. The only difference is the relative level of aggregate endowment. The type-II North has a higher aggregate endowment of talent  $E$ , which gives it comparative advantage in the more  $E$ -intensive industry  $S$ .

In all these cases, not only the relative aggregate endowment but also the correlation of endowment matters in trade. This leads to a key difference between this model and the standard H-O model. What determines the comparative advantages and trade patterns here is the effective endowments instead of the original gross endowment as in the H-O model. Effective endowment is defined as the part of original endowment that is actually utilized in production. It differs from the original multidimensional endowment because agent has to choose task and production is performed in teams. Thus part of each agent's endowment bundle is unused.

The effective endowment is determined by the original gross endowment, the agent matching process and the within-team task assignments, i.e. the choice of effective bundle and industry for each team. As we have shown in the North-North case, the correlation of endowment plays an important role in shaping the effective endowment and thus comparative advantage even with the same aggregate gross endowment. In all the cases of North-South trade shown above, the comparative advantages are determined jointly by the relative original aggregate endowment and endowment correlations. Sometimes the traditional H-O results are amplified by the effect of correlation difference, as in case 2. And sometimes the traditional H-O results are counteracted by the effect of correlation difference, as in case 3.

### 1.2.3 *Optimal Matching*

In this subsection I analyze the trade patterns under optimal agent matching. A benevolent social planner maximize the utility from goods consumption for the whole economy, given the multidimensional endowment of each agent and the production functions in two industries, by choosing the agent-matching arrangement, the task assignments and industry allocation for each team simultaneously.

#### *North-North Trade*

First consider a type-I North economy. Since there are only two type of agents in this economy, there are two possible matching schemes. One is self-matching, the other is cross-matching. Under self-matching scheme, agents with the same talent endowment are matched together. Under cross-matching scheme, agents with different talent endowments are matched together.

The social planner chooses the optimal agent matching arrangement from the self-matching scheme, cross-matching scheme, or a mix of two schemes. When self-matching scheme is chosen, the effective talent bundles in this economy will be half  $(H, H)$  and half  $(L, L)$ . When cross-matching scheme is optimal, all teams have the same effective bundle

$(H, L)$ , again due to the simplifying assumption that both industries are  $E$ -intensive.

Under the optimal arrangement, it is convenient to work with the production possibility frontier (henceforth PPF) for each economy. The possible PPFs for this type-I North economy under each matching scheme are shown below in Figure 6:

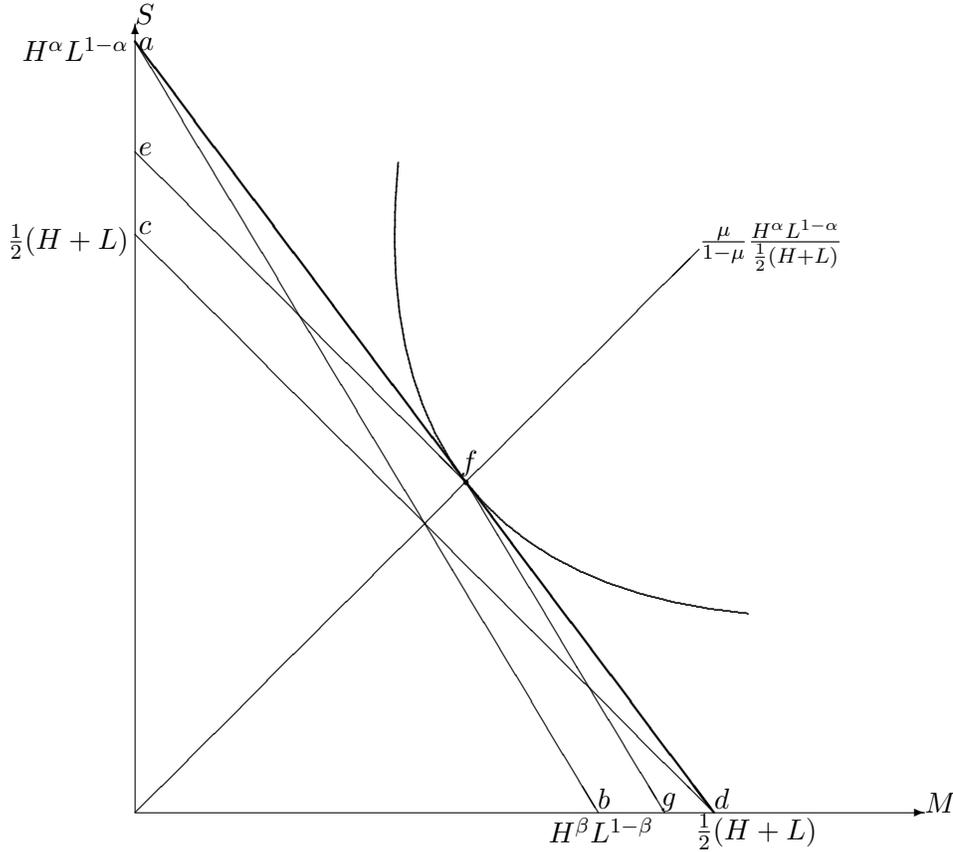


Fig. 1.6: Optimal Matching for the Type-I North Economy

The line  $ab$  is the PPF under the cross-matching scheme, line  $cd$  is the one under complete self-matching scheme. Line  $fg$  is parallel to  $ab$  and  $ef$  is parallel to  $cd$ . Thus  $efg$  is the PPF under certain mix of the two schemes. In the case shown above in Figure 6, there is no dominant matching scheme for the social planner.<sup>26</sup>

$$H^\alpha L^{1-\alpha} > \frac{1}{2}(H + L) > H^\beta L^{1-\beta}$$

<sup>26</sup> There may be dominant matching scheme in other cases. For instance, when  $\alpha$  and  $\beta$  are very close to 0.5, it is possible that  $H^\alpha L^{1-\alpha}$  and  $H^\beta L^{1-\beta}$  are both less than  $\frac{1}{2}(H + L)$ . In this case, the self-matching scheme dominates. This is similar with assortative matching in assignment models.

This condition ensures that there is no dominant matching scheme for this economy.

Even without a dominant matching scheme, the social planner can still achieve any possible production point on the line  $ad$  by choosing a proper mix of the two schemes. As a result, the line  $ad$  is the PPF faced by the social planner in this economy.

In autarky, the social planner in this type-I North economy chooses a mix of two matching schemes to achieve a particular point on the line  $ad$  to maximize the utility of consumption. Given the consumer preference on goods consumption, the equilibrium relative price of  $S$  will be determined by the reciprocal of (the absolute value of) the slope for line  $ad$ , which is  $\frac{H^\alpha L^{1-\alpha}}{\frac{1}{2}(H+L)}$ .

Given that  $H^\alpha L^{1-\alpha} > \frac{1}{2}(H+L)$  in the case of no dominant matching scheme, the absolute value of this slope is greater than one. Hence the relative price of  $S$  in this economy under autarky  $P = \frac{\frac{1}{2}(H+L)}{H^\alpha L^{1-\alpha}}$  is smaller than one.

When there is a dominant matching scheme, the relative price of  $S$  will be  $P = \frac{H^\beta L^{1-\beta}}{H^\alpha L^{1-\alpha}} < 1$  when cross-matching dominates; and 1 when self-matching dominates.

In a type-II North economy, the optimal matching scheme is always the cross-matching scheme. This is because two teams with effective talent endowment  $(H, H)$  will always outperform two teams with effective endowments  $(H, L)$  and  $(L, H)$  in any industry. Hence the PPF faced by the social planner in a type-II North economy is always the one under complete cross-matching, a negative 45 degree line. Thus the relative price of  $S$  always equals one under autarky.

Notice that in all the cases, the relative good price of  $S$  in type-I North is always less or equal to one under autarky, with equality holds only when the self-matching scheme dominates, i.e. when  $H^\alpha L^{1-\alpha} < \frac{1}{2}(H+L)$ . In most cases, the type-I North economy has a lower price for good  $S$  than the type-II North. Thus the type-I North has comparative advantage in the  $S$  industry. Only when the self-matching scheme also dominates in the type-I North economy, the two prices for good  $S$  in two economies will equal. Only in that case, there is no incentive to trade between these two economies.

In general, when these two types of North economies open to trade, the type-I North

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economy has comparative advantage in the industry  $S$  with a more extreme talent intensity. And the type-II North economy has comparative advantage in the  $M$  industry with a modest talent intensity. Analogously, when there is another industry with very high  $W/E$  intensity, the type-I North economy will also possess the comparative advantage in that industry. A more general theory for this mechanism shaping the trade patterns between these two types of North economies when there is a continuum of industries is presented in the section 3.

### *North-South Trade*

Again, I first look at a type-I South economy. The social planner also chooses the agent matching scheme from self-matching, cross-matching, or a mix of the two schemes. Under the self-matching scheme, agents with the same talent endowment are matched together. Hence half of the teams have effective bundle  $(H', H)$  and the other half have effective bundle  $(L', L)$ . Under cross-matching, agents with different talent endowment are matched and all teams choose the same effective bundle  $(H', L)$ , due to the assumption that the  $E$  intensities for both goods are greater than  $1/2$ . The PPFs for each matching scheme are shown in the Figure 7 below.

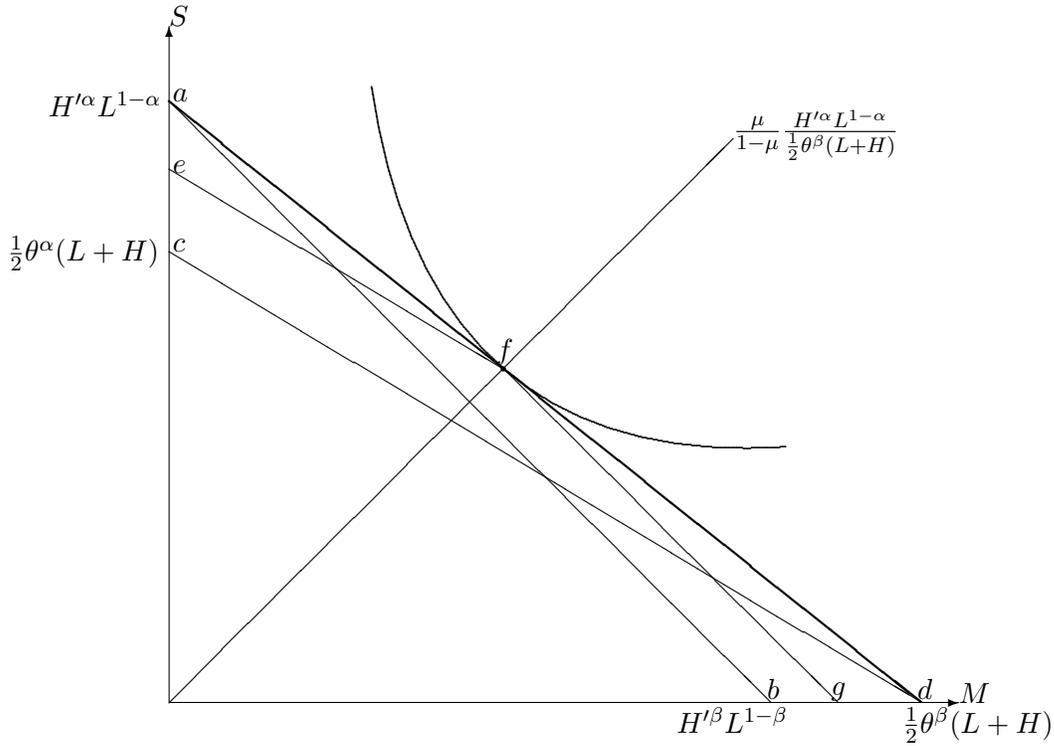


Fig. 1.7: Optimal Matching for the Type-I South Economy

The line  $ab$  is the PPF under complete cross-matching scheme; The line  $cd$  is the PPF under the self-matching scheme; And the  $efg$  is the PPF under certain mix of the two matching schemes. In the case shown in Figure 7,  $H^\alpha L^{1-\alpha} > \frac{1}{2}\theta^\alpha(L+H)$  and  $\frac{1}{2}\theta^\beta(L+H) > H^\beta L^{1-\beta}$ , there is no dominant agent matching scheme. Again, as in the type-I North economy, the social planner here can achieve any outcome along the line  $ad$  by choosing proper mixes of two matching schemes, hence the thick line  $ad$  is the PPF faced by the social planner.

Notice that the conditions for no dominant matching scheme in this type-I South economy can be simplified into:

$$H^\alpha L^{1-\alpha} > \frac{1}{2}(L+H) \text{ and } \frac{1}{2}(L+H) > H^\beta L^{1-\beta}$$

which is the same as the conditions for no dominant matching scheme in the type-I North economy.

Consider the trade between the type-I North and type-I South economies, for the type-I South economy, when there is no dominant agent matching scheme, the social planner chooses a best mix of two schemes to achieve the equilibrium production point (also autarky consumption point) at  $f$ . The relative price for good  $S$  is  $P^* = \frac{\theta^\beta \frac{1}{2}(L+H)}{\theta^\alpha H^\alpha L^{1-\alpha}} = \frac{\theta^\beta}{\theta^\alpha} P$ . Since  $\theta^\beta > \theta^\alpha$ , this price<sup>27</sup>  $P^*$  is greater than that of a type-I North economy  $P$ . North has comparative advantage in industry  $S$ .

When  $\frac{1}{2}(L+H) > H^\alpha L^{1-\alpha}$ , the self-matching scheme dominates in both economies. The autarkic price for  $S$  equals one in the North, the price for  $S$  in the South is  $\frac{\theta^\beta}{\theta^\alpha}$ , which is greater than one. In this case, South still possesses comparative advantage in the  $M$  industry. When  $H^\beta L^{1-\beta} > \frac{1}{2}(L+H)$ , the cross-matching scheme dominates in both economies. The autarkic price for  $S$  in the South is  $\frac{H'^\beta L^{1-\beta}}{H'^\alpha L^{1-\alpha}} = \frac{\theta^\beta}{\theta^\alpha} \frac{H^\beta L^{1-\beta}}{H^\alpha L^{1-\alpha}}$ . Since  $\frac{\theta^\beta}{\theta^\alpha} > 1$ , the South still possesses the comparative advantage in industry  $M$ .

Now consider the trade between the type-I South and type-II North economies, the relative price for good  $S$  is always 1 in the type-II North economy. In cases when there is no dominant matching scheme or the cross-matching scheme dominates in the type-I South economy, the relative price for good  $S$  in the South may be greater or less than one. Only when the self-matching scheme dominates in the South, the relative price of good  $S$  is certain to be greater than one. Thus only in this case, the type-I South is sure to have comparative advantage in the  $M$  industry. This result is very similar as that we get under the random matching process. The trade pattern between a type-I South and type-II North may be undetermined with all informations we have here.

Finally, I consider the trade between a type-II South economy and the North economies. In a type-II South economy, the optimal matching scheme is always cross-matching, as two teams with effective talent endowment  $(H', H)$  always outperform two teams with effective endowments  $(L', H)$  and  $(H', L)$  no matter which industry they choose. Hence

<sup>27</sup> I use asterisk to denotes variables in the South whenever needed.

under autarky, the relative good price for good  $S$  is always equal to  $\frac{\theta^\beta}{\theta^\alpha}$ , which is always greater than one. Hence in the case of integration with North economies, either type-I or type-II North economy, this type-II South economy always has comparative advantage in the more  $W$  intensive  $M$  industry.

From the analysis in the previous and current subsection, we can see that very similar results are generated under the random agent matching process and the optimal agent matching chosen by a benevolent social planner. These results have universal applications.

#### 1.2.4 *Gains From Trade in the Baseline Model*

I analyse the gains from trade in this baseline model in this subsection. I compare a new source of gains from trade with the conventional gains that identified in the literature. In summary, under random matching, the two economies with different comparative advantages will gain from trade in a conventional way. When assumptions on endowment and production change, the new source of gains from trade may occur. Under optimal matching, the new source of gains from trade may still exist even under the assumptions of this baseline model.

##### *Gains from Trade in Random Matching*

Under random matching, the PPF of each economy is fixed given all the assumptions in the baseline model. This is because the share of teams are fixed, and for each team the choice of effective endowment bundle is also fixed. Thus in this baseline model, the gains from trade is the same as those already identified in the literature.

There are overall gains from trade integration in this baseline open economy model under random matching. However, the distribution of these gains across countries might be uneven. In this simple baseline model, with all the assumptions on endowment and industry intensities, we have the following lemma on gains from trade.

**Lemma 1.1.** *With random matching, the economies whose relative good price changes from autarky to integration gain from trade. The economies with the same price after integration*

*stay the same in welfare level.*

*Proof.* Without change of production technology, the production possibility frontier of each economy is not changed due to the same matching outcome and same effective talent bundle choices under random matching. This is because given the assumptions on production functions and endowment levels, the effective bundle chosen by each team is already a dominant choice for every team and for all relative good prices. An economy will gain if the new price differs from its autarky price by the revealed preference. And due to the same reason, welfare stays the same if price does not change from autarky to integration for some other economies.  $\square$

When there is a continuum of talent levels and industries, this lemma may be gone. Then there might be changes of the effective endowment, i.e. the production possibility frontier, due to the possible change of effective endowment bundle choice for each team. In that case, there exists another possible source of gains from trade generated by the option to switch effective talent bundle within each team. This new source of gains from trade differs from the conventional gains in the sense that the effective endowment changes.

#### *Conventional Gains and New Gains*

In the standard trade models, such as Ricardian model and H-O model, the production and trade patterns in the open economy are determined by the endowments and technology. Each economy utilize all of its endowments to achieve the highest consumption (welfare) under autarky. The difference in the autarkic good prices across countries provides an incentive to trade. Each country will gain from the trade integration as consumers can consume goods at a lower price index and total output increases because more resources are allocated into its comparative advantage industries. This form of conventional gains from trade still exists in my model. However, in this framework, it is the effective endowment instead of the initial endowment that determines the production and trade patterns. These conventional gains from trade come from the change of prices and reallocation of the utilized

endowments. In my model, a new source of gains originates from the change in the effective endowment itself.

As previously shown in this paper, the effective endowment is determined by the initial endowment, the agent-matching scheme and the task-assignment on each team. When open to trade, because of the price changes, the social planner may choose to change the agent matching outcome or switch task assignment within teams to improve the overall usage of initial endowment. For example, think of a small type-I North economy with no dominating matching scheme under autarky, the relative price of  $S$  is  $P = \frac{\frac{1}{2}(H+L)}{H^\alpha L^{1-\alpha}}$ , which is less than one in this case. When it opens up to trade with the rest of the world, suppose the world price for good  $S$  is greater than  $P$ , then this small type-I North economy will completely specialize in producing good  $S$ . It will change the mix matching scheme into complete cross-matching. In this way, this economy improves its usage to its initial endowment. Notice that, when there is dominant agent matching scheme, then effective endowment can not be achieved by changing agent matching outcome when open to trade.

To show how the effective endowment can be improved by changing within team task assignment, I need to assume another industry  $A$  with low (less than 1/2)  $E$  intensity but high  $W$  intensity. Again consider a small type-I North economy, suppose now the cross-matching scheme is dominant, then all teams are formed by two agents with different endowment bundles. Then the effective bundle chosen by teams operating in the  $S$  industry and  $M$  industry is  $(H, L)$ , and the effective bundle chosen by teams operating in the  $A$  industry is  $(L, H)$ . Suppose the world prices for good  $M$  and  $A$  are both lower than autarkic prices in this small type-I North economy, and price for good  $S$  is higher than the autarkic price in this economy, when open to trade this economy will shift all its resources (teams) into the  $S$  industry. This reallocation of existing teams is a conventional way to gain from trade. Since cross-matching is a dominant matching scheme, it can not improve effective endowment through agent re-matching. Instead what it can do is changing the effective talent bundles for those teams moving from industry  $A$  to industry  $S$ , that is changing all those effective bundles  $(L, H)$  into  $(H, L)$  through task re-assignment within those teams.

Through this change, the final output of good  $S$  is improved.

The following part of the paper presents two examples of this new gains from trade. The existence of this new source of gains from trade in a general model is presented in section 3.

### *The New Gains From Trade: Examples*

The new gains from trade in my model originates from the change of the effective endowments, either through re-matching the agents or re-assigning the tasks within teams. To clarify, I present two examples for each of the two cases.

Let  $\alpha > \frac{1}{2} > \beta$ , and suppose in the type-I North economy the cross-matching scheme is dominant. Then the PPF for this economy is shown in Figure 8. Thus the teams in this economy have the same effective talent bundle choices,  $(H, L)$  or  $(L, H)$ . For those teams entering the  $S$  industry the bundle  $(H, L)$  is preferred, and for those producing  $M$  the bundle  $(L, H)$  is chosen. The equilibrium allocation of teams determines the equilibrium effective endowment in this economy.

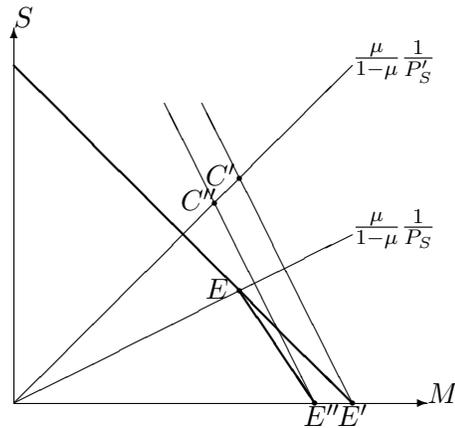


Fig. 1.8: The Switch of Effective Bundles in a Type-I North Economy

As shown in Figure 8,  $E$  is the equilibrium under autarky. When open to trade, suppose that the world price of good  $M$  is higher ( $P'_S < P_S$ ), then this economy will completely specialize in the  $M$  industry. If the teams can not switch the effective talent bundle by

changing the task assignment within teams, then the equilibrium in the open economy will be  $E''$  and consumption is  $C''$ . However, if the teams moving from  $S$  industry to the  $M$  industry are able to switch their effective bundles by re-assigning the tasks within teams, the open economy equilibrium will be  $E'$  and consumption  $C'$ . The consumption at  $C'$  is strictly better than that at  $C''$ . Thus this economy gains from the switching of effective talent bundles within teams.

In the optimal matching process for a type-I North economy, when there is no dominant matching scheme, the social planner chooses a proper mix of the two matching schemes to maximize the welfare of the economy overall. The PPF for the social planner is the line  $ad$ . In contrast, if the social planner is not able to change the agent matching outcome after opening to trade, the PPF faced by her will be an inferior set below  $ad$ . Hence, allowing possible agent re-matching introduces potential gains from trade.

Preceding are examples of gains from trade through agent re-matching and within team task re-assignment. I now present an example of another possible gains from trade in my framework, which is very similar with those in scale economies.

Consider again a type-I North economy, under the optimal matching, the PPF facing the social planner is  $ad$  as shown in Figure 9 for the case when there is no dominant matching scheme. And  $f$  is the optimal production point chosen by the planner under autarky.

When open to trade,  $efg$  will be the PPF in the open economy for this country if the cost of breaking up existing teams and forming new teams is infinite. Suppose now the planner is able to create a market platform for those broken up agents to form new teams with a fixed cost. Then the total cost of breaking up existing teams and forming new teams features decreasing return to scale. The more teams a planner chooses to break up, the less the average cost. Then the PPF facing this social planner consists of two curves starting from the autarky point  $f$ , which is  $e'fg'$  in Figure 9:

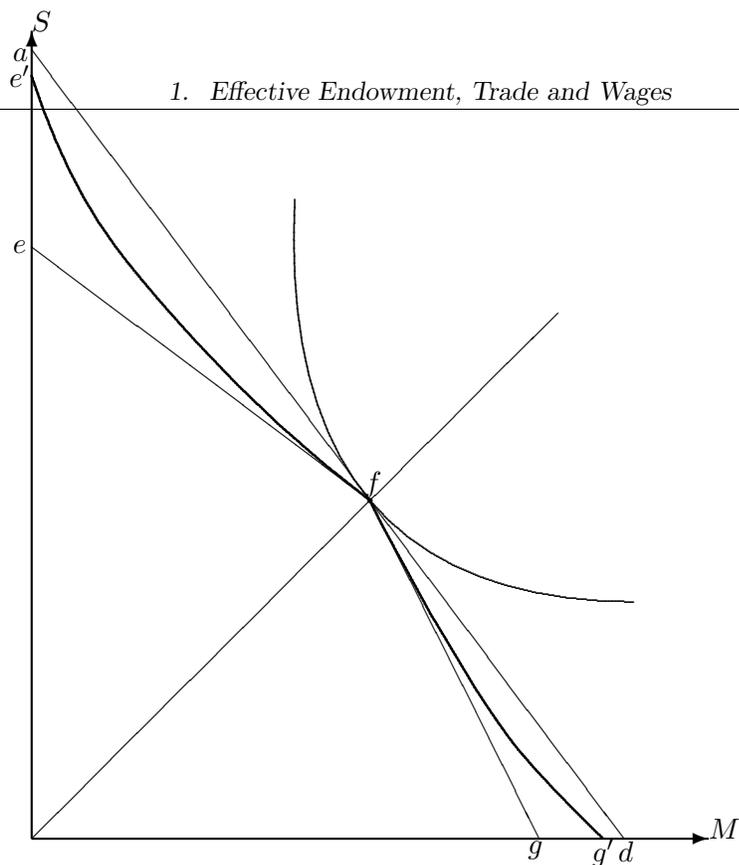


Fig. 1.9: From Autarky to Trade: Agent Re-Matching with Cost

Notice that, in this case, the production possibility set for this country after opening to trade is a non-convex set.

The non-convexity of the production possibility set is similar with the one in scale economy models. Thus this potential new source of gains from trade also resembles that in scale economy models. However, the mechanism behind the gains here is totally different from that in scale economy models. Again this extra source of gains from trade comes from the potential changes of the utilized effective endowments in this economy. In contrast, the gains in scale economies come from the increasing return to scale in production.

I summarize the differences and parallels between this framework and scale economies in generating a non-convex production set, hence the extra gains from trade. First, production is performed in teams here, in contrast individuals produce in the scale economy model. Second, the production technology features constant returns to scale in this model while increasing returns to scale in the scale economy model. Third, agents on each team perform asymmetric tasks here. The extra gains from trade disappears if tasks on the teams are

symmetric, as in Grossman and Maggi (2000). Fourth, the talent endowment for agent is multi-dimensional and each agent has to trade-off between utilizing different dimensions of their talents. Thus the effective endowment that are actually being used is not the initial endowment. In contrast, in the scale economies, there is no occupational choice and the entire initial endowment is utilized.

### 1.2.5 Wages and Job Polarization

In this subsection, I turn to another important question in the open economy, which is the effect of trade on the wages and employment.

The key intermediate step to investigate this problem is to determine the surplus division within teams.

#### *Wage Determination*

In the random matching case without re-matching after separation, each matched team will enter into production and divide the output evenly within teams. This is because when they bargain on their shares of surplus, they both have the same zero payoff in case of separation as the threat point. When there is search, then separated agents can enter the matching market and form new teams again. In this case, the threat points of each agent depends on the expected value of her endowment bundle.

In the type-I North economy, agent with endowment  $(H, H)$  has probability 0.5 to be matched with a  $(H, H)$  agent and 0.5 to a  $(L, L)$  agent. Suppose that she has a bargaining power of  $\gamma$  when she is matched with  $(L, L)$ , thus her wage is  $\gamma H^\alpha L^{1-\alpha}$  and agent  $(L, L)$ 's wage is  $(1 - \gamma)H^\alpha L^{1-\alpha}$ . When  $(H, H)$  is matched with a same type agent, her payoff is simply  $0.5H$ ; when  $(L, L)$  is matched with a same type agent, his payoff is  $0.5L$ .<sup>28</sup>

Assume a extreme case that search cost is zero, then the value of the separation option is  $0.5\gamma H^\alpha L^{1-\alpha} + 0.25H$  for agent  $(H, H)$  and  $0.5(1 - \gamma)H^\alpha L^{1-\alpha} + 0.25L$  for agent  $(L, L)$ .

<sup>28</sup> For simplicity, I neglect the good prices in the autarky analysis, assuming relative price equals one. This is a convenient short-cut in comparing the autarkic wage inequality levels for the two types of North economies.

The efficient bargaining solves the following problem by choosing  $\gamma$ :

$$\operatorname{argmax} (\gamma H^\alpha L^{1-\alpha} - (0.5\gamma H^\alpha L^{1-\alpha} + 0.25H)) ((1-\gamma)H^\alpha L^{1-\alpha} - (0.5(1-\gamma)H^\alpha L^{1-\alpha} + 0.25L))$$

Solving this problem gives the efficient bargaining outcome for agent  $(H, H)$ :

$$\gamma_1 = \frac{1}{2} + \frac{H - L}{4H^\alpha L^{1-\alpha}}$$

Similarly, in the type-II North economy, when agent  $(H, L)$  is matched with a  $(L, H)$  agent, she gets  $\gamma H$  and her partner gets  $(1-\gamma)H$ . When she is matched with a same type agent, they both get  $0.5H^\alpha L^{1-\alpha}$ ; when two  $(L, H)$  agents are matched, they each gets  $0.5L^\beta H^{1-\beta}$ . The efficient bargaining solves the following problem by choosing  $\gamma$ :

$$\operatorname{argmax} (\gamma H - (0.5\gamma H + 0.25H^\alpha L^{1-\alpha})) ((1-\gamma)H - (0.5(1-\gamma)H + 0.25L^\beta H^{1-\beta}))$$

Solving this problem gives the efficient bargaining outcome for agent  $(H, L)$ :

$$\gamma_2 = \frac{1}{2} + \frac{H^\alpha L^{1-\alpha} - L^\beta H^{1-\beta}}{4H}$$

Following the assumptions in the baseline model, it is obvious that:

$$H > H^\alpha L^{1-\alpha} > L^\beta H^{1-\beta} > L.$$

Thus the wage inequality between two types of agents is higher in the type-I North economy than in the type-II North economy. The intuition is that in the type-II North economy, low correlation means for every agent has his own specialization, no one is significantly dominated by the other in all dimensions. Thus the bargaining power allocation within teams is closer to equalization because of the lower endowment correlation. In contrast, in the type-I North economy, agent with endowment  $(H, H)$  outperforms agent  $(L, L)$  in both entrepreneurial ability and working skills dimensions. As a result, there is higher inequality

level in the type-I North economy than in the type-II North economy in equilibrium due to different correlations.

In a competitive environment under optimal matching, since there are many teams of the same type in a particular industry, each agent on the team gets the share that she contributes to the total team surplus. This is because there many teams with the same agent endowments. There is no searching cost, each team can find many alternatives for any one of its member. In this case each agent's wage is determined by the industry intensity and the total team surplus.

For the type-I North economy, I consider different optimal matching arrangements for the social planner. If pure self-matching dominates, then relative price of  $S$  relative to  $M$  is 1. Agent  $(H, H)$  gets a wage  $\frac{1}{2}H$ , and agent  $(L, L)$  gets  $\frac{1}{2}L$ .

If pure cross-matching dominates, relative price for  $S$  will be  $P_s = \frac{H^\beta L^{1-\beta}}{H^\alpha L^{1-\alpha}}$ . In the  $S$  industry,  $(H, H)$  type agents get a wage  $\alpha H^\beta L^{1-\beta}$ , and  $(L, L)$  agents get  $(1 - \alpha)H^\beta L^{1-\beta}$ . In the  $M$  industry,  $\beta H^\beta L^{1-\beta}$  is the wage for  $(H, H)$  agents and  $(1 - \beta)H^\beta L^{1-\beta}$  for  $(L, L)$  agents.

If the optimal matching is a mix of the two, the relative good price is  $P_s = \frac{\frac{1}{2}(H+L)}{H^\alpha L^{1-\alpha}}$ . In the  $S$  industry,  $(H, H)$  agents get  $\alpha \frac{1}{2}(H + L)$  and  $(L, L)$  agents get  $(1 - \alpha)\frac{1}{2}(H + L)$ . In the  $M$  industry,  $(H, H)$  agents get  $\frac{1}{2}H$  and  $(L, L)$  agents get  $\frac{1}{2}L$ .

For the type-II North economy, cross-matching always dominates. In the  $S$  industry, wage for  $(H, L)$  agents is  $\alpha H$ ,  $(1 - \alpha)H$  for  $(L, H)$  agents; In the  $M$  industry,  $(H, L)$  agents get  $\beta H$  and  $(L, H)$  agents get wage  $(1 - \beta)H$ .

From these wages, we see that the wage inequality is higher in the  $S$  industry. The high-correlation type-I North thus also have higher wage inequality than the type-II North under optimal matching.

As we can see from the analysis in this subsection, the case of random matching with search and the competitive case yield very similar results on wages. For simplicity, when I analyse the wage and job evolutions I assume the wage determination in the competitive environment.

In order to analyse the job polarization, we need to first identify what jobs are top-wage jobs, middle-wage jobs and bottom-wage jobs. In the high-correlation type-I North economy, in most cases,<sup>29</sup> we have that entrepreneurs in  $S$  industry earn the highest wage and workers in  $S$  industry earn the lowest wage. On the other hand, entrepreneurs and workers in the  $M$  industry earn middle-level wages. For the low-correlation type-II North economy, we always have that entrepreneurs in  $S$  industry earn the highest wage and workers in  $S$  industry earn the lowest wage; Entrepreneurs and workers in the  $M$  industry earn middle-level wages.

### *Trade and Wage Inequality*

In the case of North-North trade, the type-I North has comparative advantage in the  $S$  industry, those teams with endowment  $(H, H) \otimes (L, L)$  benefit the most from this integration. They are the top-wage entrepreneurs and bottom-wage workers in this industry. The inequality in type-I North will then increase. The opposite is true for the type-II North economy. This is true when we apply this into the comparison between the US and the EU. The US has a higher inequality level than the EU because the endowment correlation shaped by the general education system in the US is higher than that in the EU shaped by the skill-specialized vocational education system in those European countries.

The more interesting case to consider is the North-South trade. From the previous analysis we know that the South economy has comparative advantage in the relatively more  $W$ -intensive  $M$  industry. Two types of North economies both have comparative advantage in the  $E$ -intensive  $S$  industry. More teams in the North will choose to move into the  $S$  industry. Since in either type of North economy,  $S$  industry has the higher wage inequality than the other industry, inequality levels increase in both economies when open to trade with the South.

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<sup>29</sup> In all cases if  $\frac{H}{L} < \frac{\alpha}{1-\alpha}$ .

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*Globalization and Job Polarization*

Over the last three decades or so, most of the North economies has experienced a pattern of job evolution, the “job polarization”. It denotes the fact that the employment growth for low-wage and high-wage jobs has increased more than those middle-wage jobs. This phenomenon has been addressed pretty well in the closed economy with the task approach by David Autor and other labor economists. Here I show that this simple baseline model may also generate such a job change pattern in the open economy, specifically in the North-South integration.

As shown in the wage determination subsection, in both types of North economies, entrepreneurs in the  $S$  industry earn the highest wages in the economy and workers in the  $S$  industry earn the lowest wages. Those entrepreneurs and workers in the  $M$  industry earn middle-level wages.

After integration with the South in the globalization era, those agents working in the  $S$  industry in the North benefit the most due to the relative price increase for  $S$ . They are the top-wage entrepreneurs and bottom-wage workers in the North. After integration there will be more such matches formed and entering the  $S$  industry in the North. As a result, the employment of these top-wage jobs and bottom-wage jobs increases relative to middle-wage jobs in the  $M$  industry. Thus a pattern of “job polarization” exist in all the North economies.

Notice that even though this “job polarization” exists in all North economies. The extent of this pattern may differ in different types of North economies. Additionally, the effects on wage evolution will definitely be different for different types of North economies. In fact, there are indeed evidences for divergent wage changes in different North economies. Autor et al (2006) documents both “job polarization” and “wage polarization” in the U.S. However, the second polarization pattern is not observed in the European countries.

All in all, this baseline model provide an alternative explanation of the job polarization using North-South trade, highlighting the potential role for globalization behind these observed labor market outcomes in the North economies.

### 1.3 The Continuous Model

In this section I present a more general model with a continuum of industries and continuous multidimensional talent endowment.

There are a continuum of industries with  $E$  intensities range from  $\underline{\alpha}$  up to  $\bar{\alpha}$ . For any particular industry with intensity  $\alpha_n$ ,  $n \in [0, 1]$ , the production function is given by:

$$Y_n = E^{\alpha_n} W^{1-\alpha_n}. \quad (1.3.1)$$

The  $n$  industries are ranked such that for  $n > n'$ ,  $\alpha_n > \alpha_{n'}$ .<sup>30</sup>

The talent endowments of agents in this economy has two dimensions:  $(E, W)$ . Each follows a distribution with probability density function  $g(E)$  and  $h(W)$  respectively,  $E \in [\underline{\omega}, \bar{\omega}]$ ,  $W \in [\underline{\omega}, \bar{\omega}]$ . The correlation between the two endowment dimensions is  $\rho$ ,  $\rho \in [-1, 1]$ .

#### 1.3.1 Agent Matching

I consider two different agent matching assumptions, the random matching and the social optimal matching. Under random matching, agents have incomplete information about others' endowment before matching. The matched agents observe each other's endowment bundle and then choose task assignment, i.e. the effective bundle, and industry to maximize team output. The wages within each team are determined by solving the bargaining problem. Each agent's bargaining power depends on his alternative option value, which is the expected value of his endowment bundle.

Under the optimal matching mechanism, the benevolent social planner has complete information about agents' endowments. He chooses the agent matching arrangement, the task assignments and industry choices for each team in order to maximize the aggregate social welfare, given the available industries. In this competitive environment, each agent's wage equals her share of contribution to the final output. Particularly, in the Cobb-Douglas

<sup>30</sup> A more general form of constant return to scale production function with asymmetric tasks is  $Y = \left[ \alpha E^{\frac{\sigma-1}{\sigma}} + (1-\alpha) W^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$ . I use the Cobb-Douglas form for simplicity, all the results are the same.

production case these shares of contribution to the final output equal the talent intensities.

### 1.3.2 Generalized Trade Theories

Under this new framework I reinvestigate several well-known trade theories. Generalizations of some established trade theories are found, while some other trade theories no longer exist under new settings. Also new implications on trade and wages are drawn from this new model.

The framework in this paper shares many common features with the OT paper. They investigate how agents with different talent ratios choose their industries. This model mimic their logic after teams are formed and effective bundles are chosen. When teams with effective talent bundle of different ratios choose their industries, it follows exactly the same rationale as the agents in OT model. So the key of my proof in this paper lies in the determination of effective talent bundles.

#### *The Generalized Heckscher-Ohlin Theorem*

Compare two economies, North and South, with different relative talent endowment across two dimensions. Assume the two economies have the same endowment distribution along the  $W$  dimension. The talent endowment along the  $E$  dimension is lower in the South. Other aspects of endowment distributions are all the same, such as the correlations, available industries and technologies. Particularly, for any agent in the North with endowment  $(E, W)_N = (E_i, W_i)$ ; in the South there is an agent with endowment  $(E, W)_S = (\theta E_i, W_i)$ , where  $\theta < 1$ .

**Proposition 1.1.** *Given that South has relative less endowment along the  $E$  skill dimension, ceteris paribus, the North always has comparative advantage in those industries with high  $E$  intensities.*

*Proof.* Since the only difference between two economies is that agents in the South have lower levels of  $E$  endowment. With random matching process, the agent matching outcome in two economies will be the same in the sense that for each matched team in the North with

endowments  $(E_i, W_i) \otimes (E_j, W_j)$ , there is a counterpart team in the South with endowments  $(\theta E_i, W_i) \otimes (\theta E_j, W_j)$ . When producing a particular good with  $E$  intensity  $\alpha$ , these two teams will choose effective talent bundle in the same way because

$$(\theta E_i)^\alpha W_j^{1-\alpha} \geq (\theta E_j)^\alpha W_i^{1-\alpha} \iff E_i^\alpha W_j^{1-\alpha} \geq E_j^\alpha W_i^{1-\alpha}.$$

Thus in the production possibility set along the PPF, the maximum output potential of any good in the North will be higher than that in the South by  $(\frac{1}{\theta})^\alpha$  times. Since  $\frac{1}{\theta} > 1$ , the higher  $E$  intensity  $\alpha$  is, the more increase in output potential in the North than that in the South. As a result, the North has comparative advantage in those industries with high  $E$  intensities.

Under the optimal matching, consider any pair of goods with  $E$  intensities  $\alpha_i$  and  $\alpha_j$ ,  $\alpha_i > \alpha_j$ . Given the optimal output of a good in the South, the North can always increase the output potential of that good by at least  $(\frac{1}{\theta})^{\alpha_i}$  times through the increase of the talent  $E$  level, without changing the agent matching outcome or task assignments. Since North has a higher level endowment of  $E$  talent, the optimal matching and task assignment there allow it to utilize more of its  $E$  talent. More high level  $E$  talent endowment will be actually utilized. In this case, the higher the  $E$  intensity of an industry, the more output of it can be improved in the North from the optimal matching in the South. Hence again the relative output of the two industries  $\alpha_i$  and  $\alpha_j$  is always higher in the North than the South. This ratio is even higher under the optimal matching than that under the random matching process. Thus the North economy always has a PPF more in favor of those more  $E$  intensive goods than the South.  $\square$

In the standard H-O theorem, a country will export goods that use its abundant factors intensively, and import goods that use its scarce factors intensively. As shown by Proposition 1, this H-O theorem still hold with multidimensional endowment.

**Proposition 1.2.** *Assume the same  $W$  endowment in both economies and less  $E$  in the South, ceteris paribus, the effective endowment along the  $W$  dimension in the South is*

*always higher or equivalent to that in the North.*

*Proof.* This lemma directly follows from proposition 1. Under random matching, the two economies have the same effective endowment along the  $W$  dimension, since for each pair of randomly matched teams in two economies their choice of effective bundles are the same, as shown in the proof of proposition 1. Under optimal matching, the North economy is more willing to sacrifice some  $W$  talent to utilize the higher level  $E$  talent than the South. As the North and South have the same endowment distribution along the  $W$  dimension, in the optimal matching equilibrium the South ends up with a relatively higher effective endowment of  $W$  talent than the North.  $\square$

This proposition is to emphasize the importance of effective endowment. In this new framework with multidimensional endowment, it is the effective endowment that determines the trade patterns. And for two economies with same aggregate original endowment, their effective endowments that are actually utilized in production may differ. Thus it is important to investigate how the effective endowment is generated in different economies. This paper takes a first step in this direction.

### *Factor Price Equalization*

In the H-O model, the relative prices for two identical factors of production in the same market will eventually equal each other because of competition.

However in this model, the factor prices are usually not equalized, since the return to a particular factor also depends on the factor matched with it. In the multi-dimensional endowment case, the return to a particular dimension talent also depends on the endowments along other dimensions, since they will affect the final choice of effective talent bundle. One particular dimension of talent may end up idle without any price.

Two agents from one country with the same talent endowment along all dimensions tend to have the same (at least expected) return. However, two agents with the same talent endowment in countries with different endowments may differ in their expected returns, due to the different pools of potential team mates they are able to find.

### *The Generalized Stolper-Samuelson Theorem*

In the H-O model, a rise in the relative price of a good will lead to a rise in the return to that factor which is used most intensively in the production of the good, and conversely, to a fall in the return to the other factor.

Similarly to OT, in this model the industry choice is governed by the relative talent ratio in each team's effective talent bundle. Each matched team chooses her industry according to her effective talent ratio. When the price of a particular good  $\alpha_i$  increases, the returns to those effective bundles with this talent ratio  $\frac{\alpha_i}{1-\alpha_i}$  are increased. Since factor prices are not equalized in this framework, we can not tell as in the standard H-O model whether the return to certain dimension of talent increases or not.

### *The Generalized Rybczynski Theorem*

In standard H-O model, when only one of two factors of production is increased there is a relative increase in the production of the good using more of that factor. This leads to a corresponding decline in the relative price of that good as well as a decline in the production of the good that uses the other factor more intensively.

Within the current framework, a similar result holds. A universal increase across all agents in the endowment level of certain dimension increases the production of goods with high intensities in that talent. This is because after the increase there are more effective bundles with high ratios of that talent. Similar with OT, this means there are more teams choosing to produce goods with high intensities in that talent. On the other hand, the production of goods with small intensities in that talent shrinks.

**Theorem 1.1.** *In the framework with multidimensional endowment and team production, an increase in one dimension of talent endowment increases the relative production of goods using that dimension more intensively and decreases the relative production of goods using the other dimensions more intensively.*

*Proof.* I illustrate this theorem by doing comparative statics analysis between two equilibriums before and after the increase of talent endowment. Given equilibrium of the economy,

each team has an effective talent bundle  $(E, W)$  utilized in production of certain industry  $\alpha$ . Now consider an universal increase in the endowment levels of one particular talent dimension, without loss of generality, assume that the  $E$  talent levels are all increased by  $\lambda$  times. And  $\gamma$  is only slightly greater than 1, in order to keep all the other characteristics of endowment distribution unchanged, such as the variance, correlation etc.

Under random matching, after the talent increase the agent-matching outcome is not changed, but for each team the two choices of effective bundle both become more  $E$ -intensive. If the effective bundle choices, hence industry choices, of all teams are still the same as before the increase, then the output of industry  $\alpha$  increases by  $\lambda^\alpha$  times, where  $\alpha$  is the  $E$  intensity of this industry. In this case, the output of industries with high  $\alpha$  increases more than that of industries with low  $\alpha$  values. On the other hand, if some teams choose to switch their effective bundles and hence industry choices, it can only be the case that they are moving from less  $E$ -intensive industries into more  $E$ -intensive industries. This argument can be easily shown by contradiction. If a team moves from a more  $E$ -intensive industry to a less  $E$ -intensive industry after the increase of talent  $E$ , then they will choose that less  $E$ -intensive industry before the increase. The reason is similar with the proof of proposition 1. Hence under random matching, the Rybczynski theorem extends into this new framework.

Under optimal matching, the proof of this theorem works with the new PPF for this economy after the increase of talent  $E$ . For any pair of two goods, the increase of talent  $E$  to  $\lambda E$  increases the output possibility of all goods. And the more  $E$ -intensive a good is, the higher the increase of its output potential will be. In the end, the new PPF is more biased to those more  $E$ -intensive goods. Then the new optimal choice of output composition consists of more  $E$ -intensive goods and less  $W$ -intensive goods relative to the optimal choice before the increase. Thus the Rybczynski theorem still holds under optimal matching in the new framework.  $\square$

OT also proved a generalized version of Rybczynski theorem, which is very similar with the one shown above. There the increase of the correlation between  $s$ , the talent ratio, and

$l$ , the absolute level of the ratio, increases the relative level of high- $s$  talent bundles, hence the relative production of those goods with high-ratio intensities. Here in my framework, the increase in the level of one talent increases the ratios of that talent for all endowment bundles in this economy, resulting in more high-ratio effective bundles in that talent and thus more output of goods with high-intensity in that talent. In fact, the Theorem 4 in OT on the effect of an increase in the distribution mean of  $s$ , is very similar in effect as the mechanism presented here in Theorem 1.

### *Correlation and Trade*

There is not many measures in the literature for the correlation between endowment dimensions. But this difference do exist due to different education systems in different countries. For instance, the most recognized vocational education system in EU provide the economy with many specialized workers with some specific skills. They are proficient in performing certain tasks but poor in others. While in US education system where the general purpose technology is more emphasized provide students with general trainings in all dimensions. The difference in skills between agents in US lies more in absolute levels of skills instead of comparative differences.

The role of correlation between endowment dimensions in shaping the wage inequality has been emphasized by Gould (2002). He shows that workers in the US are increasingly finding that they are either good in all sectors or bad in all sectors. The negative effect of comparative advantage on inequality from the Roy model is decreasing in the US economy. The level of inequality is rising in US as the economy is increasingly characterized by the pursuit of absolute advantage rather than comparative advantage.

The International Adult Literacy Survey (IALS) has shown that people in different countries do have different mix of different talents/skills. The correlations do differ across countries with different education systems.

In this part, I will investigate the role of this endowment correlation in shaping the effective endowment, hence the production, comparative advantage, and trade patterns.<sup>31</sup>

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<sup>31</sup> Notice the difference between the correlation here and the one in OT. The correlation here is between

**Theorem 1.2.** *Consider a world with two economies that are identical except for the correlation between endowment dimensions  $E$  and  $W$ . (1) There exists an equilibrium. (2) In equilibrium there are two cut-off industries  $\alpha_{\underline{i}}$  and  $\alpha_{\bar{i}}$  such that the high- $\rho$  economy imports all goods with middle  $E/W$  intensities ( $\alpha_{\underline{i}} < \alpha < \alpha_{\bar{i}}$ ) and exports all goods with extreme  $E/W$  intensities ( $\alpha < \alpha_{\underline{i}}$  or  $\alpha > \alpha_{\bar{i}}$ ).*

*Proof.* Given the Theorem 3 in OT, I only need to prove that in this model the effective bundles in the high- $\rho$  country are more unequally distributed.

I show this by assuming a specific distribution for both dimensions of the talent endowment, which is the normal distribution. Particularly the talent endowment of  $E$  and  $W$  follow the following bivariate normal distribution:

$$\begin{bmatrix} E \\ W \end{bmatrix} \sim N \left( \begin{bmatrix} \mu \\ \mu \end{bmatrix}, \begin{bmatrix} \sigma_E^2 & \rho\sigma_E\sigma_W \\ \rho\sigma_E\sigma_W & \sigma_W^2 \end{bmatrix} \right), \quad (1.3.2)$$

where  $\rho$  is the correlation between  $E$  and  $W$ . When considering the role of correlation, I set  $\sigma_E = \sigma_W$  to restrict out the role of relative diversity, which will be analysed later.

Under normality the expectation of  $E$  given  $W$  is

$$\xi(E|W) = \mu + \rho \frac{\sigma_E}{\sigma_W} (W - \mu) = \mu + \rho(W - \mu), \text{ when } \sigma_E = \sigma_W. \quad (1.3.3)$$

Similarly we also have the expectation of  $W$  given the level of  $E$ .

The two countries have the same endowment distribution along each talent dimension, the only difference is the correlation. For any two agent  $i, j$ , with talent levels  $E_i$  for  $i$  and  $W_j$  for  $j$ , they show up with the same probability in two countries. In the high-correlation country A, the corresponding talent levels along the other dimension for these two agents  $i, j$  are expected to be:  $\xi(W_i|E_i) = \rho_A(E_i - \mu) + \mu$  and  $\xi(E_j|W_j) = \rho_A(W_j - \mu) + \mu$ ; In the low-correlation country B, the corresponding talent levels for these two agents are expected

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different endowment dimensions for each agent. In OT instead, each agent's endowment is characterized by his talent ratio and the talent level. The correlation in OT is the correlation between this ratio and level for each agent.

to be:  $\xi(W_i|E_i) = \rho_B(E_i - \mu) + \mu$  and  $\xi(E_j|W_j) = \rho_B(W_j - \mu) + \mu$ , where  $\rho_A > \rho_B$ .

Given  $E_i$  and  $W_j$ , the (expected) talent ratio for the other potential talent bundle for this team is

$$R \equiv \frac{E_j}{W_i} = \frac{\rho(W_j - \mu) + \mu}{\rho(E_i - \mu) + \mu}. \quad (1.3.4)$$

We are interested in the role of  $\rho$  in this ratio, taking derivative with respect of  $\rho$ , we have

$$R' = \frac{\partial \frac{E_j}{W_i}}{\partial \rho} = \frac{(W_j - E_i)\mu}{[\rho(E_i - \mu) + \mu]^2}. \quad (1.3.5)$$

When  $E_i > W_j$ , we have  $\frac{E_i}{W_j} > R$  for any value of  $\rho \leq 1$ ,<sup>32</sup> and  $R' < 0$ , thus the high-correlation country A has another bundle of smaller  $E/W$  ratio than country B. As a result, the range of talent ratios is larger in country A than in country B.

When  $E_i < W_j$ , we have  $\frac{E_i}{W_j} < R$  for any value of  $\rho$ ; and  $R' > 0$ , thus the high-correlation country A has another bundle of higher  $E/W$  ratio than country B. As a result, the range of talent ratios is again larger in country A than in country B. The rest of the proof mimics the Theorem 3 in OT.

At the end, with identical talent distribution along each single dimension, the high-correlation country has comparative advantage in industries with extreme talent intensities while the low-correlation country has comparative advantage in middle  $E/W$  intensities.  $\square$

Thus even with different definition of correlations, both my model and OT find an important role for the higher moment of endowment distributions in international trade. This point will be further emphasized in the next part about the effect of diversity on trade.

### *Diversity and Trade*

The role of endowment diversity has been shown by GM by assuming two different production technologies: the super-modular and sub-modular technology. This part investigate the role of endowment diversity in this new framework.

<sup>32</sup> To see this point,  $\frac{E_i}{W_j} - R = \frac{\rho(E_i^2 - W_j^2) + (\mu - \rho\mu)(E_i - W_j)}{W_j(\rho(E_i - \mu) + \mu)}$ , thus  $\frac{E_i}{W_j} - R > (<)0 \Leftrightarrow E_i > (<)W_j$ .

**Theorem 1.3.** *In an open economy of two countries, suppose they have the same aggregate endowment along every talent dimension. The only difference is the diversity (variance) of the endowment distribution along certain dimension. Then the high-diversity country has comparative advantage in industries with extreme (high or low) intensities of that dimension, while the other has comparative advantage in industries with middle intensities of that dimension.*

*Proof.* Consider the case of two countries with the same aggregate endowment along all dimensions, same diversity along the  $W$  dimension, and different diversity along the  $E$  dimension. Compare the change of equilibrium from the low-diversity country (A) to the high-diversity country (B).

Under the random matching mechanism, agent matching outcome will be the same along the  $W$  dimension. For any team in country A with agents endowment  $(E_i, W_i)$  and  $(E_j, W_j)$ , there is a team in country B with agents endowment  $(E'_i, W_i)$  and  $(E'_j, W_j)$ , where  $E_i + E_j = E'_i + E'_j$ , and  $(E'_i - E'_j)^2 > (E_i - E_j)^2$ . Then the effective talent bundles in country A are  $(E_i, W_j)$  or  $(E_j, W_i)$ , and  $(E'_i, W_j)$  or  $(E'_j, W_i)$  for country B. Without loss of generality, assume  $E_i > E_j$  and  $W_i > W_j$ <sup>33</sup>, then  $E'_i > E_i$ ,  $E'_j < E_j$  the effective talent ratios has the following relationship:

$$\frac{E'_j}{W_i} < \frac{E_j}{W_i} < \frac{E_i}{W_j} < \frac{E'_i}{W_j};$$

Thus in country B, the effective bundles have more extreme ratios than those in country A. As a result, the high-diversity country B has comparative advantage in those industries with extreme talent intensities.

Under the optimal matching mechanism, again the proof is dealing with the PPFs in these two countries. For any pair of agents in country A with endowments  $(E_i, W_i)$  and  $(E_j, W_j)$ , if there is a dominating choice of effective bundle, when  $E_i > E_j$  and  $W_i < W_j$  ( $E_i < E_j$  and  $W_i > W_j$ ), then effective bundle will be  $(E_i, W_j)$  ( $(E_j, W_i)$ ) in country A and

<sup>33</sup> If instead  $E_i > E_j$  and  $W_i < W_j$ , then  $(E_i, W_j)$  is the dominant choice for any industry. In that case, we still have  $\frac{E_i}{W_j} < \frac{E'_i}{W_j}$ .

$(E'_i, W_j)$  ( $(E'_j, W_i)$ ) in country B. Country B has comparative advantage in industries with high (low)  $E/W$  intensities. When  $E_i > E_j$  and  $W_i > W_j$ , there is no dominating choice of effective bundle. Consider the output possibility of two goods, one with a high  $E/W$  intensity  $\alpha$  and the other with modest  $E/W$  intensity  $\beta$ . Country A chooses  $(E_i, W_j)$  to produce the high  $\alpha$  good, chooses  $(E_i, W_j)$  when  $E_i^\beta W_j^{1-\beta} > E_j^\beta W_i^{1-\beta}$  or  $(E_j, W_i)$  when  $E_i^\beta W_j^{1-\beta} < E_j^\beta W_i^{1-\beta}$  to produce the  $\beta$  good. For country B,  $(E'_i, W_j)$  is always chosen to produce the  $\alpha$  good, it chooses  $(E'_i, W_j)$  when  $E_i'^\beta W_j^{1-\beta} > E_j'^\beta W_i^{1-\beta}$  or  $(E'_j, W_i)$  when  $E_i'^\beta W_j^{1-\beta} < E_j'^\beta W_i^{1-\beta}$ . Notice that when country A chooses  $(E_i, W_j)$  to produce the  $\beta$  good, B will choose  $(E'_i, W_j)$ , in this case, country B has comparative advantage in the high  $E$  intensity  $\alpha$  good; When country B chooses  $(E'_i, W_j)$  and country A chooses  $(E_j, W_i)$  to produce the  $\beta$  good, this comparative advantage is amplified; When country B chooses  $(E'_j, W_i)$  to produce the  $\beta$  good, country A will choose  $(E_j, W_i)$ , country A has comparative advantage in this  $\beta$  good. Analogously, in case of two goods with one modest intensity and one high  $W/E$  intensity, similar results will be obtained, the high diversity country will have comparative advantage in the industry with high  $W/E$  intensity and the low-diversity country has comparative advantage in the industry with modest intensity.  $\square$

This theorem can be easily extended in the following way.

**Proposition 1.3.** *In an open economy of two countries, assume same aggregate endowment along every talent dimension. One country has more diverse endowment distributions along one or more dimensions than the other does. Then the high-diversity country has comparative advantage in industries with extreme (high or low) intensities of that or those dimensions, while the other has comparative advantage in industries with middle intensities of that or those dimensions.*

*Proof.* This proposition directly follows from Theorem 3. When there is a second dimension with higher diversity, it generates comparative advantage in industries with extreme intensities in this second dimension. This goes the same way with the first high-diversity dimension, since the extremely high relative intensity of one dimension corresponds to the extremely low relative intensity of the other dimension.  $\square$

Compared to GM, similar results on the role of endowment diversity are generated here. In GM, the high-diversity economy has comparative advantage in industries featuring sub-modular production technology where the complementarity between tasks is lower, while the low-diversity economy has comparative advantage in industries featuring super-modular technology where the complementarity between tasks is higher. On the other hand, in my framework, industries differ in their task/talent intensity instead of task complementarity. The high-diversity economy has comparative advantage in producing industries with extreme talent intensities, while the low-diversity economy has comparative advantage in producing goods with middle talent intensities. The U.S. has a more diverse skill (talent) distribution compared with Japan. Thus U.S. has comparative advantage in those industries requiring very intensive usage of certain talent, acting like super stars on a team. While Japan's comparative advantage lies in those industries require similar levels of various skills.

Again when compared with the model in OT, the endowment inequality comes from the increase of variances of  $s$  and  $l$ . Increase of  $s$  variance means more bundles with extreme talent ratios, while the increase of  $l$  variance with correlation held constant results in more relative production of high- $s$  goods. The diversity here denotes variances of different dimensions of talent endowment. It works similarly with the variance of  $s$  in OT.

### 1.3.3 *The New Gains From Trade*

There are new gains from trade attributed to the changes of the effective endowments in each country through two channels. First, when there is no dominant agent matching scheme, then optimal agent matching contains a proper mix of different agent matching schemes. The effective endowment can be changed by using a different mix of schemes. Moreover, assuming decreasing cost to scale for agent re-matching, the production possibility set is non-convex when there is no dominating agent matching scheme as discussed in the baseline model. This leads to another type of gains similar with the gains from trade in scale economy models.

Second, the effective endowment can be changed if for some teams there is no dominant

choice of effective bundle for all industries. Then these teams may switch their effective bundles and change industries as good prices change when opening to trade.

In the general model with continuous endowment levels and a continuum of industries, there are several conditions required for these new gains to exist. I formally state them below.

**Assumption 1.1.** *Agents have multidimensional endowment of talents; The production is performed by teams of completely specialized workers; There is a continuum of industries with different task intensities.*

**Assumption 1.2.** *There is no dominating matching scheme, thus the PPFs under different matching schemes have intersections.*

**Assumption 1.3.** *There is no dominating choice of effective talent bundle across industries for all teams along the PPF.*

**Proposition 1.4.** *Given assumptions 1, with either or both assumptions 2 and 3 hold, the new source of gains from trade will exist.*

*Proof.* This proposition directly follows the intuitions shown in the baseline model. When assumptions 1, 2, 3 hold, there will always be potential to change the effective endowment of the economy to achieve a better utilization and allocation of the initial multi-dimensional endowments. □

**Proposition 1.5.** *Given proposition 1, the countries with higher endowment correlations have higher probability to obtain these new gains from trade.*

*Proof.* With higher endowment correlation, the trade-off when choosing effective endowment bundles is relatively tied. Thus when outside conditions change, such as good price changes, there are more teams who want to change their effective bundles. Hence it is easier for this economy to gain from trade by changing the effective endowment. □

The intuition of this proposition can be connected with mobility. High correlation endowment results in close trade-off between effective bundles, which differ in talent ratios.

It is also saying these teams are more flexible in choosing effective bundles and industries. When outside conditions change, they are more mobile, thus also easier to gain from integration.

**Proposition 1.6.** *As the production specialization increases, the number of asymmetric tasks, i.e. skill dimensions, increases. Given assumption 1, ceteris paribus, there is increasing probability for the extra source of gains to exist.*

*Proof.* Given the assumption of multi-dimensional endowment, as the specialization of production increases, the dimension of talents increases,<sup>34</sup> there are more potential choices of effective bundles. Hence there will be more potential to improve when outside conditions change upon trade integration.  $\square$

#### 1.3.4 Wage Inequality and Job Polarization

As shown in the baseline model, this new framework with multidimensional endowment and team production seems promising in explaining both the job polarization in all North economies and the different wage evolutions across the developed world.

Ever since the Roy model, multidimensional endowment has drawn attention from economists. Particularly, the pursuit of comparative advantage is shown to reduce the level of inequality from what would occur in a random assignment of workers into occupations. And this comparative advantage effect depends on the correlation between endowment dimensions. Gould (2002) finds evidence that the increasing correlation in US indeed contributed to the rising wage inequality.

In this new framework, endowment correlation has richer implications not only on the trade patterns as stated in the Theorem 2 but also on wage inequality and employment changes.

Multidimensional endowment has two effects on wage inequality. The selection effect decreases wage inequality when agents can choose their tasks according to their comparative

<sup>34</sup> Each dimension could be a particular subset of different talents. The increase of dimensions gives increasing number of ways to utilize the multidimensional talents.

advantages. The endowment also provide the option value when teams bargain on the shares of final output.

In the competitive case, assume that there are many potential firms that can freely enter the market and employ each team. Thus the two agents on each team get the total surplus of that team. In a competitive environment, there are also many teams with the same effective bundle in each industry, thus each agent on the team gets the share that he contributes to the total surplus. Particularly, in the Cobb-Douglas production case, each gets a share that equals his talent intensity.

**Proposition 1.7.** *Given assumption 1, in the competitive open economy, countries with comparative advantage in those extreme-intensity industries experience a higher wage inequality level; In contrast, the wage inequality level decreases in those countries with comparative advantage in middle-intensity industries.*

*Proof.* In the competitive environment, agents' share on team surplus depends on their talent intensities. With more teams enter the extreme-intensity industries, the surplus division between team members becomes more uneven. Thus the wage inequality increases. The contrary applies to the economies with comparative advantage in middle-intensity industries.  $\square$

Blum (2008) finds that changes in the sectoral composition of the economy were the most important force behind the widening of the wage gap, accounting for about 60% of the relative increase in wages of skilled workers between 1970 and 1996. This fact seems to be in line with the above proposition. Service sector is usually recognized as a sector where personal success is more important in final output. Assuming team production, in service sector there are more teams with one superman and one sidekick. The crucial skill is more intensively used than the other. And wage gap between the superman and the sidekick is large. Thus an expansion of the service sector may results in an increase in wage inequality.

**Proposition 1.8.** *In an open economy with multidimensional endowment, assume that the industry intensities are biased toward certain dimension. The developed North has*

*higher endowment along that dimension relative to the South. Then a “job polarization” employment pattern will exist in the North after integration.*

*Proof.* When the industry intensities are truncated, i.e. biased toward certain dimension. For instance, in all industries the entrepreneurial talent is equally or more intensively used than the worker skill. And the South has relatively poor endowment in the entrepreneurial talent, thus relatively rich endowment in the worker skill. In the open economy, the North has comparative advantage in those high  $E$ -intensity industries. In the competitive environment, these industries contain agents who earns the highest and lowest wages in the North. After trade integration, these industries expand the most. Hence employment in these industries increases relative to that in industries with middle intensities.  $\square$

In most of the developed economies, a relatively higher increase in the employment of low-wage and high-wage jobs, namely the “job polarization”, has been found over the last three decades (Goos et al., 2007, 2009). Most of the researches on this pattern has been focused on the closed economy (Autor et al., 2006, 2008). Only a few tries to consider the role of trade integration (Costinot and Vogel, 2010 and Monte, 2011).<sup>35</sup> The task approach used by Autor et al. is the most recognized framework to investigate the job polarization pattern. They assume that workers on those middle wage jobs mainly perform some routine tasks, which are substitutable by machines and computers. In fact, when Dustmann, Ludsteck and Schönberg (2009) dissect the German wage structure, they find it may not be true that those middle-wage workers are the ones who mainly perform routine tasks.

Even though this employment evolution pattern, job polarization, has been found in most North economies. There is however not a common pattern of wage and inequality evolution. The stylized fact in the literature says that US has a higher inequality level than the EU. Also Autor et al (2006) also finds a “wage polarization” in the US labor market besides the job polarization. The wage increase for low-wage workers and high-wage workers

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<sup>35</sup> Costinot and Vogel (2010) needs to assume a extreme biased technology change to generate job polarization in all the North economies. Monte (2011) shows the skill-biased technology and trade integration between identical countries can produce the same pattern.

is higher than that for middle-wage workers. They propose the task approach and predict wage polarization should accompany job polarization. However, there is no strong evidence showing that wage polarization also exist in other developed North economies. The upper-tail inequality does not increase in France or Japan. In Germany, below the median, the correlation between employment and wage changes is negative rather than positive in the US.

This new framework with multidimensional endowment seems to be able to reconcile these differences. Based on Proposition 8 I argue that the common pattern of job polarization in the North may be a result of the North-South trade integration. To explain the different wage evolutions across North countries, this model embeds the difference in endowment correlations. European countries and also Japan have very specialized workers due to their education system and also labor market institutions. This low endowment correlation generates comparative advantage in middle-intensity industries, thus lower wage inequality and small or no wage polarization.

### 1.3.5 *Discussion*

In this section, I very roughly discuss several interesting implications of this model.

#### *Educational Policy*

As shown in the above analysis, multidimensional endowment plays an important role in trade and labor market. The endowment correlation and dispersion both matters. In each country, agents' talent endowments are largely shaped by its education system, thus different educational policies may have profound influence on the economy.

For example, the Germany has a very skill-specialized vocational educational system as compared with a more general-skill education system in the US. Youths in Germany are divided into schools with very different missions at a very early age (around 10), some of them are then going to secondary schools to prepare for college, while others are going to schools prepared for various vocational trainings. This early division increases the special-

ization of the German labor force, and decreases the correlation of their skill endowments. In the United States however, general purpose technology and general training are more emphasized in most liberal arts schools. Thus the correlation of talent endowment across dimensions is very high in the US. Workers with more years of education outperform those with less education in almost every dimension. As shown in my model, this difference in correlations generates comparative advantage in the service industries with extreme skill/task intensities for the US, and in manufacturing with middle skill intensities for the Germany.

Given the set of available industries, educational policies should be set in particular ways to accompany one's comparative advantage. Particularly, for countries with comparative advantage in middle-intensity industries, such as manufacturing, more diversified skill endowments are preferred. Hence education policies should encourage specialization. Government subsidies for vocational training, unemployment insurance and directed agent match are optimal choices. The reverse is true for other economies with comparative advantage in extreme-intensity industries.

As specialization increases, the dimension of talent/skills increases, an efficient education system should allocate more resources to diversify the talent endowments, in order to limit the waste of talents and increase the equilibrium effective endowments that are actually utilized in production.

### *Task Off-shoring*

The baseline model discussed in section 2 can be easily extended to allow international teams, or off-shoring certain tasks. It is interesting to consider the changes of occupational structure in each economy and its effects on the wage structure.

Consider the integration of a type-I North economy and a type-I South economy, if under autarky the self-matching scheme dominates.<sup>36</sup> Then the effective bundles are: half  $(L, L)$  and half  $(H, H)$  in the North economy, half  $(L', L)$  and half  $(H', H)$  in the South economy. When open to trade, the North specialize in the  $E$  intensity good and South

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<sup>36</sup> This case exists when  $H/L$  is not too big and talent intensities are not too extreme.

specialize in the  $W$  intensive good.

When agents in these two economies are allowed to form international teams, the optimal matching includes task off-shoring. North teams with effective bundle  $(L, L)$  and South teams with effective bundle  $(L', L)$  will break up. Each North agent with endowment  $(E, W) = (L, L)$  is matched with a South agent with endowment  $(E, W) = (L', L)$ , each new team has effective bundle  $(L, L)$ , all North agents are doing the entrepreneurial task and South agents are doing the worker task. In the world economy, the effective bundles are half  $(H, H)$ , half  $(H', H)$  and a unit of  $(L, L)$ . It is a welfare improvement allowing task off-shoring. In the end, there are more entrepreneurs in the North and more workers in the South.

Eeckhout and Jovanovic (2012) builds a model to investigate the occupational choice and development. Their predictions on occupational choice are similar with the model in this paper. And they do find support from the cross-country data that after integration, the high-skill countries see a disproportionate increase in managerial occupations and low-skill countries see an increase in wage work occupations.

### *Trade and Inequality*

The effect of trade integration on income inequality, particularly in developing countries, still puzzles economists. Standard theories predict that inequality increases in the North developed economies, but decrease in the South developing economics. However, empirical evidences for this effect of trade on income distribution are mixed.

This paper emphasizes the role of industrial structure in shaping the income distribution. As economies develop, they experience different stages. Industrial specialization moves from manufacturing to service. As Blum (2008) has pointed out the rise of service sector is the most important contributor to the increase of US wage inequality between 1970 and 1996. When open to trade, the structural change is accelerated in the North. Thus inequality increases. The South also specialize in some industries with extreme high intensities in its abundant talent, the inequality level may not decrease as the standard trade model predicts.

### 1.4 *Conclusions*

This paper constructs an open economy model with multidimensional endowment and team production to explain the trade patterns and wage evolutions in the US and Europe during the globalization era. The effects of endowment correlation between dimensions and skill dispersion along each dimension on the trade patterns and labor market outcomes are investigated, in the case of North-North trade and North-South trade. The implications of this model are broadly in line with the empirical facts. The main findings are as follows.

First, the higher moments of the skill distribution, the endowment correlation and the dispersion in particular, play an important role in shaping the comparative advantage besides the relative aggregate endowments. With the same aggregate endowments in each dimension, the high-correlation (high-dispersion) country has comparative advantages in industries with extreme-value task intensities; the low-correlation (low-dispersion) country has comparative advantages in those middle-intensity industries. Moreover, the endowment distribution in each country is shaped by its educational system. Given similar aggregate endowment, the general-skill education system in the US and the skill-specific vocational education system in continental Europe result in a higher endowment correlation for agents in the US, which further generates comparative advantages in industries with extreme task-intensities. A higher dispersion in the US amplifies this effect. This simple model is able to explain the different trade patterns and wage inequality between the US and Europe, highlighting the effects of different educational policies in these two regions.

Second, it is the effective endowment instead of the initial endowment that determines the equilibrium in each economy. The effective endowment can be adjusted by reshuffling the agent-matching outcome or switching the task assignments within teams. These potential adjustments of the effective endowment provide a new source of gains from trade that differ from those conventional gains from trade identified in the literature.

Third, this model is able to generate a universal job polarization pattern in all developed countries along with different wage evolutions across the US and Europe as empirically found. Particularly, this model generates job polarization in the North economies in the

case of North-South trade under reasonable assumptions. This is in line with the fact that the job polarization pattern took place roughly in the era of globalization, when the South economies open up to trade with the North. Hence this model indicates a role for globalization behind the job polarization pattern, complementing the existing explanation based on routine-task substitute technology changes in the labor literature. Furthermore, this model also emphasizes divergent wage evolutions across North economies accompanying the common job polarization pattern. It suggests that the absence of wage polarization in Europe, but not in the US, may be a result of the lower endowment correlation and lower skill dispersion due to its vocational education system compared to the general-skill education in the US.

This framework can be adopted to investigate many interesting questions. Several applications of the model have been considered in this paper, such as the educational policy, task off-shoring and the effect of trade on wage inequality. There are also interesting empirical implications that might lead to promising empirical exercises when proper datasets are available. For example, in the case of North-South trade, the best managers and worst workers in the North benefit the most. Thus within the broad manager occupation, inequality increases. On the other hand, the inequality within the worker occupation decreases. The reverse is true for the South economy. These qualitative implications calls for more rigorous empirical investigations in the future.

The current model is also simplified in several ways and can be further extended. The agent matching process in this model is not specified in detail given the purpose of current paper is to determine the trade patterns. In reality agents are able to direct their searches towards particular jobs based on their endowments and the matching outcome may differ. The search model is worth investigation because it links to possible labor and trade policy interventions to improve efficiency. Unlike the adjustment costs discussions of the earlier literature (Leamer (1980), Feenstra and Lewis (1994), etc.), inefficiencies related to team production and matching appear to be long lasting and thus especially suitable targets for policy. Moreover, the team production organization is also extremely simplified. The team

size is fixed. In contrast, many papers have pointed out that the size of the production unit is usually bigger in manufacturing than in services (Buera and Kaboski (2012) for example). The size of teams may also be endogenously chosen by different firms. For countries with high-correlation endowment distributions, smaller team size may be chosen so that less talents are left idle. This might introduce another dimension of effect that endowment correlation may have on comparative advantages across countries. A more detailed and micro-founded modelling of the team production seems promising and will be pursued in my future research.

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## 2. MARKET SEGMENTATION, SORTING WITH MULTIPLE DIMENSIONS OF ASYMMETRIC INFORMATION

### 2.1 *Introduction*

Ever since the seminal paper by Akerlof (1970) was published, the role of asymmetric information in various markets has been investigated by many economists. Up until now, we still have limited knowledge about asymmetric information and are often lacking in ways to deal with it. This paper propose a framework to solve, at least partially, the problem of information asymmetry using the interaction between two negatively correlated dimensions of private information across segmented markets. This framework can be easily generalized and adopted in many circumstances. A labor market case is taken for example in presenting this framework.

Consider a standard labor economy, production is performed by manager-worker pairs with supermodular technology. Before the production stage, managers and workers need to be matched into pairs. From the large assignment literature, positive assortative matching will be efficient given the supermodular technology.<sup>1</sup> In most of these papers, only the efficiency of assignment is considered, there is no information asymmetry about agent types. With private information about agent types, matching will be random in the labor market. Every manager (worker) is expected to meet with a worker (manager) of the average type. Those good managers (workers) will be discouraged to enter the market.

To solve the problem of information asymmetry, I need to create incentives for agents of different types to endogenously sort themselves out. I first segment the labor market into two different industries with different production functions, which differ in their manager/worker intensities. Thus there is a manager-intensive industry and another worker-

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<sup>1</sup> See Becker (1973), Shimer and Smith (2000) among others.

intensive industry.

The type information for each agent is private, only the whole distribution of manager (worker) types is public information. Due to the information asymmetry, each manager (worker) observes only her own type, i.e., quality or skill level. Managers and workers randomly meet and match with each other.<sup>2</sup> Hence before entering segmented market, i.e. industry, and matching with partner, each agent expects to meet with a partner of the average type.

Output is then obtained for each matched pair of manager-worker. When dividing the surplus, I assume for simplicity that the bargaining power for manager against worker is exogenously given. Each manager can claim  $\theta$  share of the output for each matched pair, and the worker gets the rest  $1 - \theta$  share.<sup>3</sup> Now consider the best type manager who expects to match with an average type of worker. Given the bargaining outcome, she wants to maximize the total output of her match. Since the expected manager/worker relative type is high, she will choose to locate in the manager-intensive industry. Similar considerations apply to other types of managers and also workers. In the end, good managers locate in the manager-intensive industry, poor managers locate in the worker-intensive industry; And good workers locate in the worker-intensive industry, poor workers locate in the manager-intensive industry. Thus good managers are matched with poor workers and produce in the manager-intensive industry, good workers are matched with poor managers and operate in the worker-intensive industries.

The two dimensions of private information are the manager type and worker type for each matched pair. By construction, they are negatively correlated across different industries with different manager/worker intensities. With market segmentation, i.e. sub-

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<sup>2</sup> The search problem is not considered in this paper, matching is assumed random for simplicity. It is not crucial for this framework to work in dealing with information asymmetry. It will only affect the matching outcome within each segmented market.

<sup>3</sup> A more realistic assumption is that the bargaining power depends on the industry intensities of each agent. Thus in manager-intensive industries, managers have bigger power, and vice versa. In this case, there is another effect, denoted by bargaining effect, which works in the same way as the comparative advantage effect. Both of them make those better managers (workers) choose to locate in manger-intensive (worker-intensive) industries.

market for different industries,<sup>4</sup> managers (workers) face a trade-off between entering the manager-intensive (worker-intensive) industries and matched with a worse worker (manager), and entering the worker-intensive (manager-intensive) industries and matched with a better worker (manager). This trade-off endogenously sorts the managers (workers) into different segregated markets by their types. After sorting in the segmented markets, the problem of information asymmetry is mitigated. The average manager (worker) type in the manager-intensive (worker-intensive) industries is higher than that in those worker-intensive (manager-intensive) industries. When the number of segmented markets increase, this endogenous sorting effect can be strengthened and the market equilibrium may converge to the one with complete information.

This framework can easily be generalized and applied to deals with information asymmetry in many other circumstances, such as the asset market and the insurance market. There are two important features in this framework. First, there are multiple dimensions of private information; Second, there exists segmented markets that differ in their rewards to different agent types, and the rewards to these dimensions are negatively correlated within segmented markets. Such that there is no single market that dominates the others. With these two features, endogenous sorting is possible. To ensure its existence, three other conditions are required. First, the markets need to be segmented far enough from each other; Second, there must be no dominant industry choice for all types of agents in the aggregate matching market; Third, the dispersion of two type distributions are not too large, i.e. the worst partner is not too bad.

The intuition of this framework is similar with Guerrieri and Shimer (2012) for asset market. Agents have private information about the quality of their assets and also the liquidity they desire from the assets. The asset market has been segmented into two submarkets, one with higher liquidity and the other with low liquidity. The deviation from traditional asymmetric information literature is that, agent not only cares about the price of her asset, but also the liquidity of the asset. The segmented markets value asset quality

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<sup>4</sup> I use industries and segmented markets interchangeably in this labor market example.

and provide liquidity in different ways. Particularly, one values quality but provides low liquidity and the other devalues the asset quality but offers high liquidity. It is reasonable to argue that good asset holders are willing to wait for longer time for a decent offer, while bad asset holders would like to sell the asset as quickly as possible. With this market segmentation, each agent faces a trade-off between entering the high quality asset market with low liquidity and the low quality asset market with high liquidity. In the end, assets in the high quality asset sub-market contains assets with higher average quality.

This paper is also related with papers on the efficiency of assortative matching. Following Gary Becker, there are many papers considering the efficiency of assortative matching with transferable utility and non-transferable utility, see Adachi (2003), Burdett and Wright (1998), Legros and Newman (2007), Shimer and Smith (2000), Smith (2006) for example. The utility function, i.e. the production function here, is also non-transferable and super-modular. The different assumption here is that the production function is not symmetric. Their types are utilized with different intensities. And further because of this asymmetry, there are heterogeneous technologies. Thus the efficiency depends not only on the agent matching, but also on the choice of technology for each match. In this case, even the conditions on utility function are satisfied in those aforementioned papers, the assortative matching may not be efficient. The efficiency comparison in this case is only touched by a simple example in this paper, a more complete analysis is relegated to another paper. Instead, this paper focuses on the framework to deal with the asymmetric information problem.

This paper is organized in the following way. Section 2 presents the basic framework using a detailed labor market example. The general structure of the framework is then characterized in section 3, several applications of the framework under other circumstances are relegated to section 4. Section 5 contains further discussion and the final conclusion.

## 2.2 The Labor Market Model

### 2.2.1 Environment

There is an atomless continuum of managers, each indexed by her exogenously given productivity type  $x \in [\underline{x}, \bar{x}]$ ; and another continuum of workers, each indexed by his exogenously given productivity type  $y \in [\underline{y}, \bar{y}]$ . The measure of managers and workers are both normalized to unity. The cumulative type distribution for managers is given by  $G(x)$ , the one for workers is given by  $H(y)$ ;  $g(x)$  and  $h(y)$  are the corresponding density functions.

**Production:** There are two industries available. The production functions are both supermodular,<sup>5</sup> with constant return to scale. Two industries differ in their intensities in the manager's skill and the worker's skill. In particular, the two production functions are given by:

$$F_1(x, y) = F(x^\alpha, y^{1-\alpha}); \quad (2.2.1)$$

$$F_2(x, y) = F(x^\beta, y^{1-\beta}); \quad (2.2.2)$$

where  $\alpha > \beta$  are the intensities for manager type in two industries. Hence industry 1 is more manager-intensive, and industry 2 is more worker-intensive. One can think of industry 1 as the service industry where manager's idea and creativity are more crucial for success, and industry 2 as the manufacturing industry where the worker's skill is more important in actually producing the products.

**Preference:** Matching is random, each agent maximizes her expected pay-off by choosing the industry. For each pair of manager and worker, they have to bargain within pairs to decide how to divide the team output. For simplicity, I assume that the bargaining power for managers is  $\theta$ , and  $1 - \theta$  for workers. Thus each manager is expected to get a  $\theta$  share of the final output. Denote the price for good 1, relative to good 2, by  $p$ .

The labor market is segmented by these two industries. Agents have to search in different sub-markets, i.e. industries, to find a partner to produce output. Denote the set of managers

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<sup>5</sup> I do not consider the case for submodular technology in this paper, even though it seems quite analogous to the supermodular case. Team production is more relevant when the manager and worker's skills are complementing each other.

in industry 1 by  $\Psi_1$  with measure  $\lambda_{\Psi_1}$ ; the set of managers in industry 2 by  $\Psi_2$  with measure  $\lambda_{\Psi_2}$ ; the set of workers in industry 1 by  $\Phi_1$  with measure  $\lambda_{\Phi_1}$ ; the set of workers in industry 2 by  $\Phi_2$  with measure  $\lambda_{\Phi_2}$ . Given random matching, let  $M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})$  and  $M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})$  denote the measure of matched manager-worker pairs in industry 1 and 2 respectively:

$$M_i(\lambda_{\Psi_i}, \lambda_{\Phi_i}) \leq \min\{\lambda_{\Psi_i}, \lambda_{\Phi_i}\}, \quad i = 1, 2.$$

I also assume the matching technology features constant return to scale. Within industry  $i$ , the probability of being matched for each manager in industry  $i$  is given by  $M_i(\lambda_{\Psi_i}, \lambda_{\Phi_i})/\lambda_{\Psi_i}$ ; the probability of being matched for each worker in industry  $i$  is given by  $M_i(\lambda_{\Psi_i}, \lambda_{\Phi_i})/\lambda_{\Phi_i}$ . The expected pay-off function for a type  $x$  manager,  $W(x)$  can then be written as:

$$\theta \max \left\{ p \frac{M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})}{\lambda_{\Psi_1}} \int_{y \in \Phi_1} F(x^\alpha, y^{1-\alpha}) dy, \frac{M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})}{\lambda_{\Psi_2}} \int_{y \in \Phi_2} F(x^\beta, y^{1-\beta}) dy \right\}; \quad (2.2.3)$$

The expected pay-off of a type  $y$  worker,  $W(y)$  can also be written as:

$$(1 - \theta) \max \left\{ p \frac{M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})}{\lambda_{\Phi_1}} \int_{x \in \Psi_1} F(x^\alpha, y^{1-\alpha}) dx, \frac{M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})}{\lambda_{\Phi_2}} \int_{x \in \Psi_2} F(x^\beta, y^{1-\beta}) dx \right\}. \quad (2.2.4)$$

Good price  $p$  is determined in the equilibrium supply of two goods and consumer preference on goods consumption. The utility function is given by:

$$U = C_1^\mu C_2^{1-\mu}. \quad (2.2.5)$$

where  $C_1$  and  $C_2$  are consumption of good 1 and good 2 respectively.

In the closed economy that I consider, the equilibrium consumption of each good equals the output in each industry. Thus given the agent output, the relative good price  $p$  is given

by:<sup>6</sup>

$$p = \frac{\mu}{1 - \mu} \frac{Y_2}{Y_1}, \quad (2.2.6)$$

where  $Y_i$  is the total output of industry  $i$ .

Within each industry, the expected total output is given by:

$$Y_1 = \frac{M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})}{\lambda_{\Psi_1} \lambda_{\Phi_1}} \int_{x \in \Psi_1} \int_{y \in \Phi_1} F(x^\alpha, y^{1-\alpha}) dx dy; \quad (2.2.7)$$

$$Y_2 = \frac{M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})}{\lambda_{\Psi_2} \lambda_{\Phi_2}} \int_{x \in \Psi_2} \int_{y \in \Phi_2} F(x^\beta, y^{1-\beta}) dx dy. \quad (2.2.8)$$

**Strategies:** Due to the information asymmetry about agent types, each agent expect to meet with a partner of the average type in each labor market. The best type manager is also expected to be matched with an average type worker. Given the good prices and bargaining power  $\theta$ , she wants to maximize the expected output of her match. Since she knows her own manager type, which is the highest, her match is expected to have a high ratio of manager/worker type, which results in a comparative advantage in the more manager-intensive industry. As a result, she will choose to enter the more manager-intensive industry 1. Similar strategies can be obtained for other types of managers and workers. In the end, relatively better managers tend to enter industry 1 while those poor managers choose industry 2; relatively better workers tend to enter industry 2 while those poor workers choose industry 1.

These strategies have two effects. First, they create another effect that amplifies the initial incentive for pursuing the comparative advantage. This is because the original sorting generates a set of lower (on average) worker types in industry 1,  $\Phi_1(y)$ , a set of higher manager types in industry 1,  $\Psi_1(x)$ ; and also a lower set of manager types in industry 2,  $\Psi_2(x)$ , a higher set of worker types in industry 2,  $\Phi_2(y)$ . Compared with the original agent types in the aggregate labor market, the comparative advantage of matches in each industry

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<sup>6</sup> As it will be shown that the endogenous good price is used to pin down a interior, stable sorting equilibrium. There are also rich applications when good prices are exogenously given. For instance, when a firm with establishments producing different goods is employing managers and workers, the good prices will be taken as given by all managers and workers. Thus for most of the analysis in this paper, good prices are assumed to be exogenous.

is amplified. Good managers' comparative advantage in the manager-intensive industry 1 is amplified. Poor managers' comparative advantage in the worker-intensive industry 2 is also amplified. Thus this effect makes high-quality agents stay in the industry that is intensive in their own skills, and low-quality agents move to the other industry that is intensive in their partners' skills.

Second, these strategies also generates poorer partners for those high-quality agents who stay in industries that are intensive in their skills. In industry 1, there is a lower set of worker types  $\Phi_1(y)$ , hence also lower expected output, for all high-quality managers in this industry. On the other hand, there is a higher set of worker types  $\Phi_2(y)$  for all low-quality managers in industry 2. This effect moves more low-quality managers (workers) into the worker-intensive (manager-intensive) industry.

In the end, those lower type workers (managers) are attracted to locate in industry 1 (2), while higher type workers (managers) stay in industry 2 (1). In the equilibrium, each agent chooses an industry according to her quality. Thus a kind of sorting is obtained. Additionally, within each submarket, i.e. each industry, the average type of managers is closer to the true types than that of the aggregate labor market. In this sense, the problem of information asymmetry in the aggregate labor market is mitigated by segmenting the aggregate market.

Particularly, in equilibrium, there is a cutoff manager (worker) type that divides all types of managers (workers) into two groups. Better managers and worse workers search for partners in industry 1; and worse managers and better workers search for their partners in industry 2. The amount of managers may differ with the number of workers in a particular industry. Thus there might be unemployment. The distribution of agent types is public information. I present the general equilibrium with information asymmetry in the next subsection. And compare it with the complete information equilibrium in the following subsection.

Before diving into the equilibrium characterization, it is useful to go through the intuition for why the endogenous sorting happens. There exist two industries with different

manager/worker intensities. By construction, the team-production assumption creates a negatively correlated rewards system for the two dimensions of private information, the manager type and the worker type. The manager type is more valuable in the manager-intensive industry, but the worker type is more valued in the worker-intensive industry. One can not have the highest payoff for her own type and the best partner at the same time. For different types of agents, this trade-off differs across industries, thus sorting by agent types may happen.

### 2.2.2 The Sorting Equilibrium with Asymmetric Information

Each agent's type information is only privately observed. However, the type distributions of all workers and managers are public information.

I use  $x^* \in [\underline{x}, \bar{x}]$  to denote the cutoff manager type, those managers with types equal or above  $x^*$  choose to enter industry 1 and those below  $x^*$  type managers choose to locate in industry 2. Thus  $\Psi_1 = [x^*, \bar{x}]$ ,  $\lambda_{\Psi_1} = 1 - G(x^*)$ ; and  $\Psi_2 = [\underline{x}, x^*)$ ,  $\lambda_{\Psi_2} = G(x^*)$ .

The cutoff type for workers is denoted by  $y^* \in [\underline{y}, \bar{y}]$ , workers with better quality than  $y^*$  choose to stay in industry 2 and those with types below  $y^*$  move to industry 1. Thus  $\Phi_2 = [y^*, \bar{y}]$ ,  $\lambda_{\Phi_2} = 1 - H(y^*)$ ; and  $\Phi_1 = [\underline{y}, y^*)$ ,  $\lambda_{\Phi_1} = H(y^*)$ .

Within the segmented labor market in each industry, managers and workers meet randomly. Thus given those two cut-off types  $x^*$  and  $y^*$ , the probability of finding a partner for any manager in industry 1 is given by:

$$P_x^1 = \frac{M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})}{\lambda_{\Psi_1}} = \frac{M_1(1 - G(x^*), H(y^*))}{1 - G(x^*)};$$

The probability of finding a manager for each worker in industry 1 is given by:

$$P_y^1 = \frac{M_1(\lambda_{\Psi_1}, \lambda_{\Phi_1})}{\lambda_{\Phi_1}} = \frac{M_1(1 - G(x^*), H(y^*))}{H(y^*)}.$$

Analogously, in industry 2, the probability of finding a worker for any manager is given

by:

$$P_x^2 = \frac{M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})}{\lambda_{\Psi_2}} = \frac{M_2(G(x^*), 1 - H(y^*))}{G(x^*)};$$

And the probability of finding a manager for any worker is given by:

$$P_y^2 = \frac{M_2(\lambda_{\Psi_2}, \lambda_{\Phi_2})}{\lambda_{\Phi_2}} = \frac{M_2(G(x^*), 1 - H(y^*))}{1 - H(y^*)}.$$

In equilibrium, the manager (worker) of the cutoff type is indifferent between locating herself in industry 1 and industry 2. Thus we have the following two equations for these two types of managers and workers respectively:

$$p \frac{P_x^1}{H(y^*)} \int_{\underline{y}}^{y^*} F((x^*)^\alpha, y^{1-\alpha}) h(y) dy = \frac{P_x^2}{1 - H(y^*)} \int_{y^*}^{\bar{y}} F((x^*)^\beta, y^{1-\beta}) h(y) dy; \quad (2.2.9)$$

$$p \frac{P_y^1}{1 - G(x^*)} \int_{x^*}^{\bar{x}} F(x^\alpha, (y^*)^{1-\alpha}) g(x) dx = \frac{P_y^2}{G(x^*)} \int_{\underline{x}}^{x^*} F(x^\beta, (y^*)^{1-\beta}) g(x) dx. \quad (2.2.10)$$

where  $g(x)$  and  $h(y)$  are the probability density functions corresponding to  $G(x)$  and  $H(y)$ .

Equation (9) and (10) above pin down the two equilibrium cutoff types for the endogenous sorting of managers and workers across the two industries.

Given the cutoff type of managers (workers), those better types will choose to stay in the manager-intensive (worker-intensive) industry, this is because:

$$p \frac{P_x^1}{H(y^*)} \int_{\underline{y}}^{y^*} F(x^\alpha, y^{1-\alpha}) h(y) dy > \frac{P_x^2}{1 - H(y^*)} \int_{y^*}^{\bar{y}} F(x^\beta, y^{1-\beta}) h(y) dy;$$

$$p \frac{P_y^1}{1 - G(x^*)} \int_{x^*}^{\bar{x}} F(x^\alpha, y^{1-\alpha}) g(x) dx < \frac{P_y^2}{G(x^*)} \int_{\underline{x}}^{x^*} F(x^\beta, y^{1-\beta}) g(x) dx.$$

for all  $x = x^* + \epsilon$ ,  $y = y^* + \epsilon$ , where  $\epsilon > 0$  is a tiny positive term such that all the measure terms are not changed. For managers of a slightly better type than  $x^*$ , given the zero measure of each particular type of agents in this economy, they have higher expected payoff in the manager-intensive industry. The opposite is true for managers of a slightly worse

type. This is because:

$$\left(\frac{x}{x^*}\right)^\alpha > (<) \left(\frac{x}{x^*}\right)^\beta \text{ for } x > (<)x^*, \text{ when } \alpha > \beta; \text{ and } F \text{ is increasing in } x, y.$$

This simple proof can be carried out recursively for all other types different from the cutoff type. Thus the optimal industry choice, i.e. segmented market choice, for agents of different types is continuous in their types except for the cutoff type. Thus the two cutoff types are able to pin down a agent-industry allocation equilibrium. Following this logic, the following lemma straight forward in a general case.

**Lemma 2.1.** *If a type  $x$  manager chooses the industry with manager intensity  $\alpha$ , a type  $x'$  manager locates in the industry with manager intensity  $\alpha'$ , and  $x > x'$ , then it must be the case that  $\alpha \geq \alpha'$ .*

**Lemma 2.2.** *If a type  $y$  worker chooses the industry with worker intensity  $\beta$ , a type  $y'$  worker locates in the industry with worker intensity  $\beta'$ , and  $y > y'$ , then it must be the case that  $\beta \geq \beta'$ .*

**Equilibrium Existence:** The equations (6)-(10) pin down the equilibrium solutions for cutoff types  $x^*$  and  $y^*$  with endogenous good prices. When good prices are exogenously set in the world economy or outside of this labor market, there may exist multiple equilibria. Consider the two extreme cases, in one case where all types of managers and workers locate in industry 1; in the other case all types of managers and workers choose industry 2. In the first case,  $x^* = \underline{x}$  and  $y^* = \bar{y}$ ; in the second case,  $x^* = \bar{x}$  and  $y^* = \underline{y}$ . In both cases, given either of  $x^*$  and  $y^*$ , the other is the optimal choice. These two extreme cases are indeed equilibria of industry choices with exogenous good prices. The question now is if there is any equilibrium with interior cutoff types, in which case agent sorting arises.

**Sorting equilibrium:** The equilibrium is a sorting equilibrium when managers and workers endogenously choose their industries according to their own types, and both segmented markets are not empty.

As long as the equilibrium solutions for  $x^*$  and  $y^*$  are not corner solutions, the equilib-

rium features endogenous sorting of managers/workers by their types. And the resulting equilibrium is a sorting equilibrium.

**Existence of Sorting Equilibrium:** Conditions for the existence of sorting equilibrium when good prices are exogenous: (1) Two industries differ enough in their skill intensities, i.e.  $|\alpha - \beta|$  is large enough; (2) There is no dominant (or dominated) industry choice for all types of agents in the aggregate labor market; (3) The dispersion of two type distributions are not too large.

The first condition ensures that the comparative advantage effect across industries is strong enough to induce different industry choice by agents of different types given the type distributions. The second condition restricts the type distributions, so that there is no dominant industry choice for all types given the two industries. When pursuing one's comparative advantage by choosing a industry that values her skill relatively more, she faces the loss of being matched with a worse partner. The third condition ensures that the worse type is not that bad. Thus the opportunity cost is not too big relative to the benefit of the comparative advantage effect.

Now consider the general case when good prices are endogenously determined in this economy. I will show that there exist unique interior solutions for  $x^*$  and  $y^*$  that pin down a sorting equilibrium for this economy.

**Theorem 2.1.** *Equations (6)-(10) pin down the equilibrium solutions to  $x^* \in (\underline{x}, \bar{x})$  and  $y^* \in (\underline{y}, \bar{y})$ , which characterize a sorting equilibrium of industry (sub-market) choices. Managers with quality higher than  $x^*$  and workers with quality lower than  $y^*$  locate in the manager-intensive industry 1; Managers with quality lower than  $x^*$  and workers with quality higher than  $y^*$  choose the worker-intensive industry 2. Within each industry (sub-market), the problem of asymmetric information is mitigated.*

*Proof.* Using the two lemmas, we can rewrite equation (7) and (8) with  $\Psi_1 = [x^*, \bar{x}]$ ,  $\Psi_2 = [\underline{x}, x^*)$ ,  $\Phi_2 = [y^*, \bar{y}]$ , and  $\Phi_1 = [\underline{y}, y^*)$ . Then we have:

$$\frac{\partial Y_1}{\partial x^*} < 0, \text{ and } \frac{\partial Y_2}{\partial x^*} > 0.$$

From equation (6), we then have:

$$\frac{\partial p}{\partial x^*} > 0.$$

Notice that  $\frac{\partial P_x^1}{\partial x^*} > 0$  and  $\frac{\partial P_x^2}{\partial x^*} < 0$  if the matching technology has constant return to scale.

Rewrite equation (9) as:

$$\frac{\int_{\underline{y}}^{y^*} F((x^*)^\alpha, y^{1-\alpha}) h(y) dy}{\int_{y^*}^{\bar{y}} F((x^*)^\beta, y^{1-\beta}) h(y) dy} = \frac{1}{p} \frac{P_x^2}{P_x^1} \frac{H(y^*)}{1 - H(y^*)}.$$

Given  $y^*$ , the left hand side of the above equation (LHS) is a monotonic increasing function of  $x^*$ ; The right hand side (RHS) is a monotonic decreasing function of  $x^*$ . Thus there is a unique solution of  $x^*$ . Analogously for  $y^*$ , given any  $x^*$ , there is also a unique value of  $y^*$  that solves equation (10).

Now think of an increase in  $y^*$ , the increasing function LHS will shift up for all  $x^*$  values; And the RHS decreasing function also shifts up for all  $x^*$  values due to the constant return to scale in matching technology:

$$\frac{\frac{M_2(G(x^*), 1-H(y^*))}{G(x^*)}}{\frac{M_1(1-G(x^*), H(y^*))}{1-G(x^*)}} \frac{H(y^*)}{1-H(y^*)} \text{ increases with } y^*.$$

Notice that  $\frac{\partial p}{\partial y^*} < 0$ , so the RHS indeed shifts up when  $y^*$  increases. The two shifted lines pin down a new equilibrium  $x^*$  for the increased  $y^*$ , which is also higher. In all, we have:<sup>7</sup>

$$\frac{\partial x^*}{\partial y^*} > 0.$$

Analogously we can get that  $\frac{\partial x^*}{\partial y^*}$  is also positive.

The above two response functions between  $x^*$  and  $y^*$  pin down the equilibrium solutions for the cutoff manager/worker types. Notice that there might be multiple equilibria. When  $x^* = \underline{x}$ ,  $y^* = \bar{y}$ ; the reverse is also true. When  $y^* = \underline{y}$ ,  $x^* = \bar{x}$ ; the reverse is also true. These are two corner solutions to the above equations. Other interior solutions each characterizes a sorting equilibrium.

<sup>7</sup> Notice that this is true even when the good price is exogenously given.

When good prices are endogenously determined, in equilibrium the output of both goods are positive. The equilibrium solutions are those interior solutions, which ensure that the equilibria are sorting equilibria.  $\square$

**Uniqueness and Stability:** There might be multiple equilibria. Expectation changes may change the steady state equilibrium.

**Discussion:** Increase in number of heterogeneous industries (segmented markets): The higher type a manager (worker) is, the larger the comparative advantage effect will be and thus the stronger incentive for her to choose a more manager-intensive (worker-intensive) industry. When sorting exists, those managers (workers) of the best types choose the most manager-intensive (worker-intensive) industry available and match with workers (managers) of the lowest types. The second best block of managers (workers) have smaller comparative advantage effect, hence less incentive for manager-intensive (worker-intensive) industry. They choose a industry with the second highest manager (worker) intensity, matching with a block of slightly better types of workers (managers) there.

When the number of segmented markets increases, *ceteris paribus*, the extent of sorting increases. The true types of agents in each segmented market become more and more accurately represented by the intensities in each market. Thus we no longer need to costly evaluate or screen for the agents' true types. When the number of segmented markets is large enough, the sorting might be maximized.<sup>8</sup> Agents of different types locate in different industries. In this case, industry intensities ordinaly represents each type of agents. The problem of information asymmetry about agent types is thus partially solved.

An increase in the dimensions of information asymmetry makes it easier to find two negatively correlated subsets of information dimensions, hence making it easier to generate a sorting equilibrium.

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<sup>8</sup> Several conditions are required for this perfect sorting to happen, I relegate these conditions to the next section.

### *Multiple Industries*

When there are multiple industries, the sorting effect may be amplified. Rank the industries by their manager intensities, which are denoted by  $\alpha_i$ ,  $\alpha_i > \alpha_{i'}$ , for  $i < i'$ ,  $i, i' = 1, 2, \dots, N$ .

The potential cutoff types are denoted by  $x_j^*$ ,  $j = 1, 2, \dots, N - 1$  for managers and  $y_j^*$ ,  $j = 1, 2, \dots, N - 1$  for workers. Managers of types between  $[x_1^*, \bar{x}]$  and workers of types in  $[\underline{y}, y_{N-1}^*]$  enter the most manager intensive industry  $\alpha_1$ . More generally, managers of types in  $[x_{j+1}^*, x_j^*]$  and workers of types in  $[y_{N-j}^*, y_{N-j-1}^*]$  enter the industry with manager intensity  $\alpha_{j+1}$ . From the previous lemma, it is straight forward that  $\{x_j^*\}$  and  $\{y_j^*\}$  are two decreasing sequences.

In the two industry case, when there is no sorting equilibrium there is no cutoff type. Or the cutoff type coincides with the best or worst types. In this multiple industry case, some neighboring potential cutoff types listed above may be the same and some industries will be dominated by the close one.

To pin down these cutoff types, there are  $N - 1$  indifference equations for those cutoff types managers and also  $N - 1$  equivalence relations for those cutoff types workers. Analogously with the two-industry case, the equilibrium existence and characterization for the multiple-industry case are then followed.

#### *2.2.3 The Complete Information Equilibrium*

With complete information about the agent types, this problem resembles the famous marriage problem. The only difference is that after the two-sided matching, all the matched pairs have to be assigned into the two industries with different production functions. As many economists have point out, the conventional wisdom of assortative matching is no longer efficient under these new settings. (See Kremer and Maskin (1996) among others.)

It is hard to formally characterize the efficient assignment outcome under the current labor market settings. It is not the main focus of this paper either. But some intuitions for the efficient assignment can be laid down.

The general form of the efficient assignment under the above settings features positive

assortative block matching. The best block of managers are matched with the best block of workers. Within each block, different types of agents are sorted into different industries according to their comparative advantages. And within each industry, i.e. each segmented market, the manager-worker matching is still positive assortative matching given the super-modular production function in each industry.

The number of blocks and their length are determined jointly by the industry intensities and the dispersion of type distributions. For instance, given the industry intensities, more concentrated type distribution means very few block divisions. Meanwhile, given the type distributions, more extreme industry intensities means larger length for each block.<sup>9</sup>

In a very special case, there is only one block in the efficient matching. With enough segmented industries, the best type manager and the worst type worker enter the most manager-intensive industry; the second-best manager and the second-worst worker enter the second-most manager-intensive industry; and so on and so forth. Each pair enters a unique industry. In this case, the sorting equilibrium with asymmetric information about agent types coincides with the socially efficient matching outcome.

#### *A Complete Information Example*

There are equal units of high-type managers with skill level  $h$ , low-type managers with skill level  $l$ , high-type workers with skill level  $h$  and low-type workers with skill level  $l$ . Two industries are symmetric in intensities:

$$F_1 = m^\alpha w^{1-\alpha}; \text{ and } F_2 = m^{1-\alpha} w^\alpha; \text{ where } \alpha \in [0.5, 1).$$

When  $\alpha = 0.5$ , the two industries are the same, two category of agents are symmetric in production. In this case, given this supermodular production function, positive assortative matching is efficient, i.e. high-type managers and matched with high-type workers, low-type managers and matched with low-type workers.

When  $\alpha \in (0.5, 1)$ , the assortative matching may no longer be efficient. Given the ratio

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<sup>9</sup> Note that the length for each block may not be equal, it's the type ratios that matter the most.

of  $h/l$ , the higher value  $\alpha$  is, the more likely that cross matching dominates assortative matching. While given the value of  $\alpha$ , the lower the ratio  $h/l$  is, the more likely that cross matching dominates assortative matching in efficiency.

For example, when  $l = 1$ ,  $h = 3$ , and  $\alpha = 0.6$ , cross matching yields  $2h^{0.6}l^{0.4} \approx 3.87$ , while assortative matching yields 4; If instead  $\alpha = 0.7$ , cross matching yields approximately 4.32, while assortative matching still yields 4. Thus given the ratio of  $h/l$ , the higher  $\alpha$  is, the more likely that cross matching dominated the assortative matching.

When  $\alpha$  is fixed at 0.6, and  $l = 1$ ,  $h = 2$ , cross matching yields approximately 3.03 and assortative matching yields 3; If instead  $h = 3$ , the output of cross matching is approximately 3.87, which is smaller than the assortative matching output 4. In addition, given that cross matching dominates the assortative matching, this efficiency gain is non-monotonic in the  $h/l$  ratio.

The intuitions behind are also very straightforward. When the  $h/l$  is fixed, assortative matching dominates. Notice that the assortative matching is the special case of assortative block matching, when each block only contains one type of agents; The cross matching is also a special case when there is only one block. When  $\alpha$  increases, the length of the block increases. Until it is long enough to contain both high and low type agents, there is only one block and the assortative block matching becomes a cross matching of all agents.

When  $\alpha$  is fixed, the lengths of blocks are fixed. High  $h/l$  ratios means distant agent types, thus smaller probability that both types will locate in the same block, thus assortative agent matching is more likely to dominate; Instead, low  $h/l$  ratios indicate that the two types are very close, and with higher probability to locate in the same block, thus cross matching is more likely to dominates assortative matching.

#### 2.2.4 Testable Empirical Implications

If this general framework is indeed adopted by firms or agencies in real economy to differentiate heterogeneous agents, then some empirical implications are also expected in the data.

1. *Wage Dispersion*: With only one single industry, or market, all agents in the same occupation, manager or worker, are expected to get the same amount of reward due to the information asymmetry. There is no ex-ante inequality. The ex-post inequality is all random.

With more segmented markets, there will be more endogenous sorting. Within each occupation, manager or worker, different types of agents are segmented in different sub-markets. Even within each segmented market, the skill type is still private information, the averages of skill types can be ordered by industry intensities.

Since better managers are matched with poorer workers, and vice versa, the inequality within each occupations may actually decrease.

If this framework is used only as a screening process, firms choose their workers and managers according to the sorting outcome of this process and pay them according to their true types (approximately). Then the resulting final wage inequality within occupations will increase.

Within firms/industries, more vertical specialization means more sorting, thus higher within-occupation inequality.

2. *Industry Dynamics*: As I have discussed above, for some firms or industries, the good prices may not be endogenous. There might be multiple equilibria in the choice of industries or establishments. Which equilibrium is actually obtained depends on agents' expectations. For example, if a new industry arises and all agents have high expectation about the promising future of this industry and are willing to enter this industry. Given this expectation, the equilibrium with more agents in the new industry will be more likely to come true.

This logic might be helpful to explain the observed industry boom or burst due to the adjustments of expectations.

3. *Unemployment*: In this framework, the unemployment exists if there is any coordination failure for workers and managers when choosing their optimal industry location.

Particularly, if  $G(x^*) + H(y^*) = 1$ , there is perfect coordination. In each industry, there are equal amount of managers and workers. Thus there will be no unemployment; If  $G(x^*) + H(y^*) \neq 1$ , then the amount of managers and workers in each industry will differ. And unemployment arises due to this coordination failure.

So mandate allocation of labor force or organized-direction may help to improve the decentralized market outcome.

### 2.3 *Dealing with Asymmetric Information*

In this section I characterize the general structure of the framework that can be used to deal with information asymmetry as shown above. The key features and their roles in this framework are then analyzed.

This framework creates endogenous sorting by different quality agents to deals with information asymmetry with market segmentation and interaction between multiple dimensions of information. Two important features and four crucial conditions are required for its proper functioning.

The first feature is that there are multiple dimensions of asymmetric information. When agents care about multiple dimensions of private information, potential trade-off might happen. In the labor market case, each agent not only cares about the reward on her own type, but also cares about the type of her partner. Thus the manager type and worker type are two dimensions of private information.

The other feature is the existence of segmented markets. The sub-markets are segmented in the sense that they differ in their rewards to agent quality types. In the labor market case shown above, the two industries with different output functions are acting this role. Manager type's intensities and worker type's intensities are different in different industries.

Given these two features, endogenous sorting is possible, but may still does not exist in equilibrium. To ensure its existence, four conditions are required.

Firstly, to ensure sorting there must be some trade-off between different dimensions of information. It is required that the returns to different dimensions of information are

negatively correlated within segmented markets. Thus there is no dominant sub-market. Due to the negative correlation, agents face trade-off between gaining from different dimensions in choosing segmented market. Pursuing in one dimension of information means sacrificing along the other dimension. This creates incentives for agents of different types to endogenously sort themselves out. In the labor market case, production is performed by manager-worker pairs. The constant return to scale assumption on production functions ensures that within industries the intensities of manager type and worker type are negatively correlated. Given the incentive to pursue comparative advantage each agent faces the trade-off between comparative advantage for her own type and comparative advantage for her partner's type.

Secondly, the markets need to be segmented far enough from each other. In the above labor market case, the two production functions must differ enough in their intensity structures, i.e. the difference between  $\alpha$  and  $\beta$  is large enough.

Thirdly, given the available industries, there is no dominant (or dominated) industry choice for all types of agents in the aggregate matching market. This restricts the type distributions. For instance, in an economy with very good workers and poor managers, the whole type distribution for workers is above the one for managers, then all agents have the same optimal choice to enter the worker-intensive industry.

Fourthly, the dispersion of quality distributions are not too large, i.e. the worst type agents are not too bad relative to the average type. When pursuing one's comparative advantage by choosing a industry that values her skill relatively more, she faces the loss of being matched with a worse partner. This condition ensures that the worse type is not that bad relative to others. Thus the opportunity cost is not too big relative to the benefit from the comparative advantage effect.

I summarize the framework as the following. It contains two main features that may create endogenous sorting, and four conditions to guarantee the existence of the sorting equilibrium:

**Feature 2.1. *Multiple Information Asymmetries:*** *There are multiple dimensions of*

*asymmetric information.*

**Feature 2.2. Market Segmentation:** *There are at least two segmented sub-markets.*

**Condition 2.1.** *The returns to different dimensions of information are negatively correlated within segmented markets.*

**Condition 2.2.** *Sub-markets are segmented far enough from each other.*

**Condition 2.3.** *There is no dominant sub-market choice for all types of agents conditional on individual expectation.*

**Condition 2.4.** *The dispersion of quality distributions are not too large.*

With the above structure and conditions on market segmentation and quality distributions, this framework can successfully mitigate or even solve the problem of information asymmetry. We have the following theorem:

**Theorem 2.2.** *With Feature 1 and 2, and Condition 1, 2, 3, 4 hold, there exists endogenous sorting by agent types into different sub-markets.*

*Proof.* Given the available sub-markets, condition 1 ensures that there is no dominant sub-market choice for any agent since the negative correlation creates a trade-off between different dimensions of information; Condition 2 ensures that two closely located sub-markets do not dominate each other, there are agents in every sub-market after the sorting; Condition 3 makes sure that given the available sub-markets, for any type distributions there is no dominant or dominated sub-market choice. Different type agents do have different choice of sub-market; All the previous conditions motivate the divergent sub-market choices for different types of agents, in order to pursue the comparative advantage effect in the risk of getting a worse partner. Condition 4 ensures that the cost of this pursuit is not too large. □

Following these general principles, this framework can be easily generalized and applied to many other scenarios.

## 2.4 *Applications of the framework*

In this section, I present two examples where the above framework is applied to deal with the problem of information asymmetry.

### 2.4.1 *The Example of Asset Market*

Now I apply the framework presented above in the asset market to show how the information asymmetry problem about asset quality can be dealt with.

The first key is to find out another dimension of characteristic that asset holders also value besides the asset quality. Potential candidates vary across different types of assets. Here I take financial asset for example. Due to the nature of financial assets, their prices are usually very volatile. Thus people holding financial assets not only care about the prices that they can get from for assets, but also care about how quickly they can cash out or buy back the assets. Same as the asset quality, its liquidity value that the owner attaches to it is also private information of the owner. Thus the asset liquidity is another dimension of private information.

Liquidity is usually a market phenomenon. Different markets have different level of liquidity. Suppose there are multiple markets for financial assets, each with different levels of liquidity. In order for the asset owners to endogenously sort themselves out by their asset quality, the return to two dimensions need to be negatively correlated across markets.

Assuming that high quality asset owners care less about liquidity value of the asset, the market segmentation by liquidity level can act as a sorting framework to deal with asymmetric information on asset quality. This assumption is plausible because good asset holders are willing to wait for a longer time for a decent bid on her asset, hence she values asset liquidity relatively less than bad asset holders who are eager to get rid of his assets in hand.

Thus good asset holders put their assets on the market with low liquidity, getting a higher average bid for her asset while sacrificing certain liquidity; bad assets holders list their assets on the more liquid market, receiving a lower average bid while enjoying high

liquidity.

#### 2.4.2 *The Example of Insurance Market*

In the insurance market, the problem caused by information asymmetry may be even more pervasive and severe. The pricing of various kinds of insurance programs are more complicated and most of time costly. So it will be fruitful to apply the current framework in the insurance market case.

The empirical efforts on insurance market have identified the existence of multiple dimensions of private information. For instance, Finkelstein and McGarry (2006) finds that not only the intrinsic health level but also the subjective preference for insurance affects the adverse selection in insurance purchase.

If those agents with better health conditions are in good health because they are more careful about their diet, more risk averse, etc. then they are also likely to have stronger preference for insurance. Thus these agents with better health are more willing to buy insurance. This is different from the adverse selection problem that agents with worse health conditions will buy more insurance given the price set for an average type agent. Due to the existence of the first effect, the latter adverse selection problem will be mitigated due to the improvement of health conditions of agent pool in the insurance program.

In reality, the actual pricing of different insurance programs do contains many different criteria. With any two negatively correlated criteria across target agents, the framework may work. All the insurance company need to do is set up different categories of programs for agents according to the return to one particular criterion. Due to the negative correlation, the agents will sort themselves into these segmented categories when the returns to these criteria differ enough across different insurance programs.

#### 2.4.3 *Other Cases with Team Production*

The key for this framework to work is the existence of two negatively correlated dimensions of asymmetric information. Sometimes it may be hard to find. But with team production

functions, these two dimensions of information asymmetries can be easily identified. The only assumption needed is limited degree of return to scale, such that the returns to different agent types on the team are negatively correlated within segmented sub-markets.

## 2.5 *Conclusion*

Being aware of the destructive effect that information asymmetry may have on market function, I propose a framework to deal with it. The endogenous agent sorting is generated when multiple dimensions of asymmetric information are negatively interacted in the existence of market segmentation. When the sub-markets are separated far enough and the agent type distributions are not too disperse, the sorting equilibrium exists. Agents choose different sub-markets to enter according to their true types. Within each segmented sub-markets, the problem of asymmetric information is mitigated.

As shown above, this framework can be generalized and applied to many other cases with information asymmetries.

In real businesses, firms can design their job offers in a particular way to screen, at least partially, the applicants by their qualities. For example, a firm want to hire a manager for a particular position and there are two applicants. The firm owner wants to choose a better one. She offers two positions for two applicants to choose, one position is real and the other is made-up. The real position has a production function which is very intensive in manager skill and works with limited other resources, where success largely depends on the performance of the manager on that position. Meanwhile, the made-up position has a production function that is much less intensive in manager skill and works with good supporting resources, where success does not largely depends on the manager's own ability. The two positions offer the manager the same share of claim on the final output. Given these two offers, the more talented applicant tends to choose the first offer and the less talented applicant chooses the second one. In this way, the firm can keep the better manager and let go the poorer manager. So firms can indeed screen their applicants by properly designing their job offers in a way following the framework presented in this paper.

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### 3. THE SPECIFICITY AND RETURN OF HUMAN CAPITAL: A TEAM-PRODUCTION APPROACH

#### 3.1 Introduction

The increasing worker mobility across firms, occupations and even industries, makes it more and more relevant to identify the boundary, or the specificity, of human capital.<sup>1</sup> The specificity of human capital determines the extent of human capital depreciation as workers move across firms, occupations, or industries. It also matters for the return of human capital investment.

The evidence and understanding of the specificity of human capital in the literature is still mixed.<sup>2</sup> The most recent works done by Poletaev and Robinson (2008), Autor and Handel (2009) using very detailed job-task data seem to support the idea that each job is a subset of different tasks and each task usually requires a particular type of human capital (skill).<sup>3</sup> In this paper, I follow this line of interpretation and assume that human capital is intrinsically task-specific. A particular type of human capital is used to perform a corresponding task. Based on this task-specific human capital, I investigate how can human capital acts like firm-specific, occupation-specific or industry-specific.

While most of the existing papers use a worker welfare maximization or firm benefit maximization approach to analyse the worker displacement, they do not consider the separation of worker-firm match as a two-sided problem. In the real economy, a job separation is the outcome of a two-sided choice between the worker and the firm. It can happen either

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<sup>1</sup> See, for example, Kambourov and Manovskii (2008), Poletaev and Robinson (2008) for the evidences on worker mobility across occupations and industries.

<sup>2</sup> See Becker (1962), Mortensen (1978), Jovanovic (1979), Hashimoto (1981) for analysis based on firm-specific human capital; See Kambourov and Manovskii (2009) for evidence on occupation-specific human capital; See Neal (1995), Parent (2000) for arguments on industry-specific human capital.

<sup>3</sup> Gibbons and Waldman (2004) also argue that task-specific human capital may have important implications in the labor market.

because the firm finds the worker less qualified and wants to fire him, or the worker is not satisfied with the current position and quit voluntarily. Either side can end the match between a worker and a firm. As a result, a two-sided search framework is more suitable for analysing the the worker turnover, and also the specificity and return of human capital.

In this paper, I propose a team-production approach built on a two-sided search problem with task-specific human capital to investigate the specificity and return of human capital.<sup>4</sup> It is shown that the task-specific human capital generates a firm quasi specificity under this team-production approach, which gives firms monopsony power over workers' skill and gives incentives for firms to sponsor general-skill training. This model also generates a negative correlation between the wage levels and turnover rates as empirically found.<sup>5</sup> In addition, this team-production approach provides a new microfoundation for the increasing returns in human capital accumulation.

There are two categories of heterogeneous agents in the labor market, the managers and the workers. Good production is performed in teams, with one manager and one worker on each team.<sup>6</sup> As in the classic marriage model, the managers and workers costly search for partners/teammates in the labor market. Upon meeting, the two agents observe the true type, level of human capital, of their partners. A team is formed when the match is stable, that is when both sides accept to stay. Otherwise the meeting fails and each agent continues to search for a partner in the market. Given the search frictions, matching technology and agent distributions, for each worker (manager) there is a lowest type of manager (worker) that he will accept as a partner. And also there is a highest manager (worker) type that will accept him as a partner. In the two-sided search equilibrium, it is shown that managers and workers are segregated into different clusters according to their qualities. Agents from the same cluster adopt the same search strategy, and are matched with partners from the same cluster.

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<sup>4</sup> I use human capital and skill interchangeably in this paper.

<sup>5</sup> There are some alternative explanations in the literature, see Neal (1998) and the references there for examples.

<sup>6</sup> The main interest of this paper is to analyse how each worker will make his search decision and human capital investment decision. One can think of each team as a firm, the manager on each team as the rest of the firm excluding this worker.

Given the random matching technology, every agent has the same probability of being matched. The probability of getting a stable match depends on the size of cluster one is in. It is shown in this paper that, with linear and Pareto distributions of agent quality, the sizes of clusters increase with cluster rank. In other words, high-quality agents have larger group of potential stable partners, hence a larger probability of forming a stable match conditional on each meeting. This result is in line with the empirical fact that low-skilled workers, also low-wage workers, have higher turnover rates than high-wage workers.

The human capital is only specific at the task level. So as long as a worker is performing the same task(s) in the new firm, his task-specific human capital accumulated in the previous firm is preserved and the new firm can utilize the full amount of his human capital. In this sense, the human capital is not firm-specific. However, a stable match is formed only when one's partner is good enough so that the current payoff exceeds or equals his expected payoff for searching. Once a worker is matched, his partner is expected to be an average manager from the same cluster, which is strictly better than the lowest type from this cluster. Thus his current payoff is strictly better than the expected value of search. He will leave the current firm/team only when a big enough negative shock hits his current partner; or his partner will leave him if there is a positive shock.<sup>7</sup> From this perspective, the human capital is, at least partially, specific to the current firm. This firm quasi specificity thus provides incentives for firms (teams) to provide general (across firms) skill trainings. In particular, this model highlights that firms are more willing to provide group training for each manager-worker pair.<sup>8</sup> A coordinated group/team training program can reduce the separation probability for both the manager and the worker.

In a dynamic economy with human capital accumulation, the team-production and two-sided matching in this model provide a new microfoundation for the increasing returns in human capital investment. Due to the assumed supermodular production technology, the

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<sup>7</sup> In this case, a positive shock hits his partner, or the firm, then he may be no longer acceptable by his partner or the firm. Then he will be fired by the firm.

<sup>8</sup> In real economy, firms usually provide certain particular training for each job/occupation/position. For each production unit, a group training program increases the task, also skill, specialization among team members. The increased skill levels induce higher output, and also a lower probability of separation.

return to one's human capital also depends on the quality of the partner he is matched with. Individual human capital investment has two effects. First, higher human capital level increases the probability of forming a stable match, thus the search costs she has to bear is lower; Second, in equilibrium the matching is still positively assortative-only with block segregation. In this matching equilibrium, two categories of agents are segregated into different blocks/classes. The best class workers only match with the best class managers. The matching is positively assortative in the level of different classes. As a result, in this model, human capital investment increases the stable match probability to save search costs and also increases the quality of his potential partner to increase his final output. Thus there is increasing returns to human capital investment under these settings.

This paper is related with at least four strands of literature. First, the search equilibrium derived in the model is of the same nature as those in other more general models of two-sided search presented by Burdett and Coles (1997), Block and Ryder (2000), Adachi (2003) and Smith (2006). In particular, I focus my attention to the ranges of the subintervals in equilibrium, and adopt the two-sided search into the team production framework.

Second, this paper poses a new perspective on the specificity of human capital. Similar with Gibbons and Waldman (2004) this paper assumes that human capital is task-specific. When occupation is defined as certain task, then human capital is also occupation-specific. A more general case is to think of each occupation as a weighted average of a bundle of tasks, human capital is still occupation-specific in the sense that different occupations reward certain human capital level differently. See Kambourov and Manovskii (2009), Poletaev and Robinson (2008) for other discussions on the occupational specificity of human capital. One may also view different firms demanding different weighted bundles of tasks in their production, thus also reward human capital differently. In this case, human capital is also firm-specific. This is the case considered in Lazear (2009). This paper differs from his model in generating firm-specificity using team production. Firms are essentially the same, or we can think of enough potential similar firms in the competitive market, they have the same production technology. The difference is the set of employees that they are able to

hire. All these papers can use their firm-specificity to explain the firm-sponsored general skill training. But which one is a better characterization remains an empirical question.

Third, this paper is also related with papers investigating the correlation between wage levels and turnover rates. Neal (1998) argues that it is because the high-skill agents sort themselves into more specialized jobs.<sup>9</sup> In stead, this paper focuses on how agents' skill levels-or wage levels-are correlated with their turnover rates within certain occupation and also more generally in certain industry or the whole labor market. In this model, *ceteris paribus*, high-skill agents have larger acceptance range thus higher probability of stable match. As the market frictions decrease, search costs decrease, the acceptance range shrinks. And the search equilibrium approaches the perfect positively assortative matching. In that extreme case, this correlation between wages and turnover rates disappears. Future empirical work is needed to test this proposition.

Finally, this paper complements the literature on the microfoundation for the social increasing returns in human capital investment by showing that with labor market frictions, search friction in this model, and team production, human capital accumulation not only increases the probability of getting a stable match but also increases the quality of the potential partner. This microfoundation is similar with the one shown by Acemoglu (1997). There with labor market friction, the increase in workers' human capital induces firms to coordinately provide more physical capital in production thus higher marginal output for workers' human capital, resulting increasing returns to workers' human capital accumulation. In my model, there is no physical capital but team production. The human capital accumulation of workers increase their probability successful match and also increase the quality of potential managers that may be matched with them. It works as if managers also invest in their human capital to match up with the workers.

The rest of the paper is organized as follows: Section 2 presents the main model without and with endogenous human capital investment. The analysis on specificity, correlation

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<sup>9</sup> Note that in my model, within each occupation, the high-quality agents are more specific to their current matches because of the larger clusters, hence larger loss from involuntary separation from current partners. It seems like high-quality agents are more specialized in their current jobs or firms and thus less mobile. In this sense, this model mimics Neal (1998).

between wages and turnover rates, firm general skill training, etc. are all presented following the model. Section 3 lists some testable empirical implications. And the last section concludes.

### 3.2 *The Model*

The key assumption in this model is that the production is organized in teams, with specialized team-members performing different tasks with supermodular production technology. In this paper, I assume that the team size is two for simplicity. In production, there are two different tasks need to be done to produce any good. I define the position associated with each task as an occupation.<sup>10</sup> Then there are two different occupations, manager and worker. Thus there are two categories of agents, one category are the managers and the other are the workers.

I first present a two-sided search model with team production to show the search equilibrium for agents with different quality, and use it to show the specificity of human capital, and the correlation between wage levels and worker turnover rates. After that, a model with endogenous human capital investment is built based on the two-sided search model. This model features increasing returns in human capital accumulation.

#### 3.2.1 *The Two-Sided Search Model*

The group of heterogeneous managers have a type distribution indexed on  $[0, 1]$ , with cumulative distribution function  $G(x)$ ; The group of heterogeneous workers have a type distribution also indexed on  $[0, 1]$ , with cumulative distribution function  $H(y)$ . Their density functions are denoted by  $g(x)$  and  $h(y)$  respectively. Let  $\lambda^m$  and  $\lambda^w$  denote the measure of managers and workers.

The production function for any team with type  $x$  manager and type  $y$  worker is  $F(x, y)$ , which features multiplicative separability between the manager type  $x$  and the worker type

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<sup>10</sup> In this sense, the human capital is also occupation specific. A more general and realistic case may be that each occupation is a weighted bundle of some set of tasks. But this simplifying assumption does not affect our key result, which is the quasi firm specificity generated from task-specific human capital.

$y$ . This means that  $F$  can be written as a multiplication of two functions:  $F(x, y) = f_1(x)f_2(y)$ , where  $f_1$  and  $f_2$  are concave, increasing functions of  $x$  and  $y$ .<sup>11</sup> Once output is produced, the manager gets an exogenously given  $\theta$  share and the worker gets the rest.

I consider an infinite discrete time period,  $t = 0, 1, \dots + \infty$ . At any time  $t$ , unmatched managers and workers are matched according to a simple random matching technology. In particular, given the measures of managers and workers  $\lambda^m$  and  $\lambda^w$ , the measure of matched agents is given by  $M(\lambda^m, \lambda^w)$ , where  $M$  is increasing in both its arguments and  $M(\lambda^m, \lambda^w) \leq \min\{\lambda^m, \lambda^w\}$ . The matching technology is efficient if  $M(\lambda^m, \lambda^w) = \min\{\lambda^m, \lambda^w\}$ .

The probability of being matched for any manager is then given by  $M(\lambda^m, \lambda^w)/\lambda^m$ . The probability for any manager of being matched with a worker of quality less than  $y$  is thus given by  $M(\lambda^m, \lambda^w)H(y)/\lambda^m$ . Similarly, the probability for any worker of being matched with a manager of quality less than  $x$  is given by  $M(\lambda^m, \lambda^w)G(x)/\lambda^w$ . All agents have a common discount factor  $\delta$ , which is exogenously determined by the interest rate, search frictions and others.

At each meeting, the manager and the worker simultaneously announce yes or no. If both agree to the match, the team is formed. If one of the two agents says no, they remain unmatched and enter the next round search anew. I assume that after each successful match  $(x, y)$ , there is a manager of quality  $x$  and a worker of type  $y$  flow into the market so that the distributions are time-invariant.

I now define the optimal strategy for any worker  $y$ . A strategy for worker  $y$  is a function:  $\sigma_y : [0, 1] \rightarrow \{\text{yes, no}\}$  mapping the quality of a partner (manager) into an announcement. The payoff of worker  $y$  depends on his own strategy  $\sigma_y$  and the profile of strategies of managers denoted by  $\sigma_x$ . Hence for any stationary strategy profile  $(\sigma_x, \sigma_y)$ , the expected payoff of worker  $y$  is simply  $EU_y(\sigma_y, \sigma_x)$ .

**Definition 3.1.** *A search equilibrium is a stationary strategy profile  $(\sigma_x, \sigma_y)$  such that*

- (a) *For almost all managers  $x \in [0, 1]$ , all strategies  $\sigma'_x$  for manager  $x$   $EU_x(\sigma_x, \sigma_y) \geq EU_x(\sigma'_x, \sigma_y)$*

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<sup>11</sup> One simple example is the Cobb-Douglas production function,  $F(x, y) = x^\alpha y^{1-\alpha}$ .

(b) For almost all workers  $y \in [0, 1]$ , all strategies  $\sigma'_y$  for worker  $y$   $EU_y(\sigma_y, \sigma_x) \geq EU_y(\sigma'_y, \sigma_x)$

A worker  $y$  accepts a manager of quality  $x$  if and only if  $(1 - \theta)F(x, y) > \delta EU_y(\sigma_y, \sigma_x)$ . The model I consider is essentially the same as in Block and Ryder (2000), they show that there exists a unique search equilibrium characterized by the formation of a sequence of clusters such that managers and workers only match if they belong to the same clusters.

**Theorem 3.1.** *There exists a unique search equilibrium in the two-sided search model. This equilibrium is characterized by the formation of two sequences of subintervals  $I^n = (a^n, a^{n-1}]$  and  $J^n = (b^n, b^{n-1}]$  of  $[0, 1]$  such that all manager  $x$  in the subinterval  $(a^n, a^{n-1}]$  adopt the same search strategy  $\sigma_x = (b^n, 1]$  and all worker  $y$  in  $(b^n, b^{n-1}]$  adopt the same search strategy  $\sigma_y = (a^n, 1]$ . The subintervals are defined recursively as follows:*

- $a^0 = 1$
- For any  $n \geq 1$ ,  $a^n$  is the unique solution to

$$f_1(a^n)(1 - \delta) = \delta \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{a^n}^{a^{n-1}} (f_1(x) - f_1(a^n))g(x)dx$$

and

- $b^0 = 1$
- For any  $n \geq 1$ ,  $b^n$  is the unique solution to

$$f_2(b^n)(1 - \delta) = \delta \frac{M(\lambda^m, \lambda^w)}{\lambda^m} \int_{b^n}^{b^{n-1}} (f_2(y) - f_2(b^n))h(y)dy$$

The expected value of search for any worker  $y$  in the subinterval  $(b^n, b^{n-1}]$  is given by  $V(y) = (1 - \theta)F(a^n, y)/\delta$  and for any manager  $x$  in the subinterval  $(a^n, a^{n-1}]$  by  $V(x) = \theta F(x, b^n)/\delta$ .

*Proof.* See the Appendix. □

Theorem 3.1 characterizes the unique two-sided search equilibrium in this model. In equilibrium, workers and managers are segregated into different classes such that all agents of the same class adopt the same search strategy.

The intuition underlying this theorem can be captured by considering the problem faced by the best manager. Since any worker accepts him, he faces an unconstrained problem and chooses a threshold  $b^1 < 1$  as the highest worker that he will refuse. Now all workers in  $(b^1, 1]$  is accepted by the best manager, thus all managers. These workers also face the same unconstrained search problem and choose a threshold  $a^1 < 1$ . This leads to the first cluster for high-quality agents,  $(a^1, 1] \times (b^1, 1]$ . Next we can consider the best manager left on the market  $a^1$  and the best worker  $b^1$ . A repetition of the above analysis gives us the second cluster  $(a^2, a^1] \times (b^2, b^1]$ . The complete collection of clusters can be obtained recursively by repeating the above argument.

Theorem 3.1 reflects a very interesting form of endogamy that all managers in the subinterval  $I^n$  only match with workers from the corresponding subinterval  $J^n$ . Thus only agents belonging to the same class can form stable matches. To have a direct impression on this endogamy, it is very useful to consider a simple example, where two populations are symmetric ( $\lambda^m = \lambda^w = 1$ ), agents are uniformly distributed on  $[0, 1]$  ( $g(x) = h(y) = 1$ ), and matching is efficient  $M(\lambda^m, \lambda^w) = \lambda^m = \lambda^w = 1$ . And the production function is simply  $F(x, y) = xy$ . In this case, the subintervals  $I^n$  and  $J^n$  are identical with

- $a^0 = 1$
- $a^n = a^{n-1} + \frac{\sqrt{1-\delta}(\sqrt{1-\delta}-\sqrt{1-\delta+2\delta a^{n-1}})}{\delta}$

Figure 3.1 shows the clusters formed in equilibrium of this simple example when  $\delta = 0.8$ . Notice that the sizes of clusters decrease with  $n$ . Given the uniform distribution of agent types, this also means that high-quality agents have a higher probability of being accepted and forming a stable match at each meeting. Since meeting is random for all types of agents, this means that high-quality agents have higher probability of successful match in this two-sided search problem.

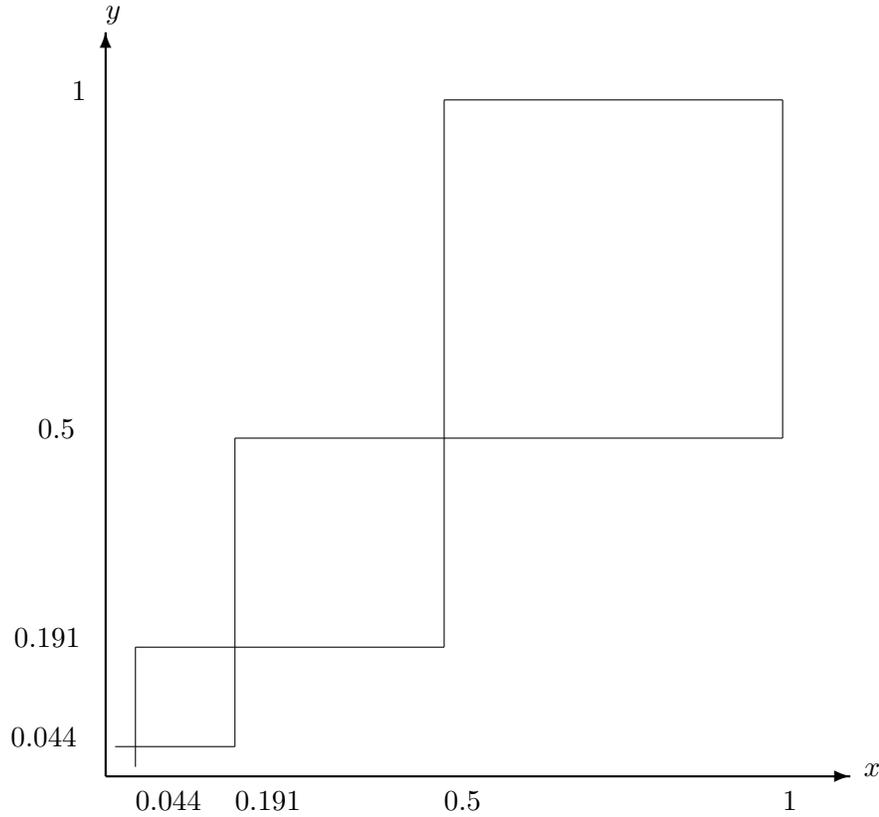


Fig. 3.1: Search Equilibrium with Uniform Distribution,  $\delta = 0.8$

Actually this is true not only when the agents' quality distributions are uniform. All linear distributions or Pareto distribution for agent types are sufficient to ensure that the sizes of clusters in the two-sided search equilibrium will decrease with  $n$ .

**Proposition 3.1.** *In the equilibrium of a two-sided search model, the sizes of clusters,  $I^n$  and  $J^n$ , decrease with  $n$  if agent types follow a Pareto distribution or any linear distribution.*

#### Wages and Turnover

Now let us consider the negative correlation between the wage levels and turnover rates. First, observe that agents' wage levels are highly correlated with their quality. From Proposition 2.3, we see that the cluster sizes decrease with  $n$ . Thus the cluster sizes also decrease with quality.

Given random meeting in the search market, larger cluster size means higher probability

of stable match for agents in this cluster. As a result, high-quality agents with larger cluster sizes can form stable match easier than low-quality agents. It follows that high-quality agents, also high-wage agents, have lower turnover rates in the labor market.

There is another way of understanding this negative correlation. Think of any stable match in equilibrium, when a random shock hits one of the partner in this two-sided match, the original match will still be stable if both partners still find each other acceptable, i.e. if both partners still belong to the same cluster. Due to the larger range of clusters for high-quality agents, the high-quality match is more stable against the shocks to agent qualities.

As we can see from above, in this simple two-sides search model, it is natural that the wage levels and worker turnover rates are negatively correlated.

### *The Specificity of Human Capital*

In this subsection, I will first show how the firm specificity arises in this model from task-specific human capital and team-production; and then show the incentives for firms to provide general skill trainings for their employees.

Recall that in this paper, the human capital is only task-specific. In the above simple model, there are only two tasks, i.e. two occupations in production. Thus task-specific is the same as occupation-specific here. Managers have managerial skills and workers have working skills. Skills, or human capitals, are task-specific but not firm-specific in the sense that any agent with certain skill level can fully utilize his whole skill in every firm. But due to the team-production, output depends on both partners' skill levels, the same human capital level may be rewarded differently across firms. As a result, human capital acts like firm-specific, or more accurately match-specific (specific to the current partner or current firm if we think of the rest of the firm as the partner of certain employee).

Notice in Theorem 3.1, in the equilibrium of this two-sided search problem, the expected value of search for any worker  $V(y)$  (manager  $V(x)$ ) in each cluster is the corresponding payoff in a match with the lowest type manager (worker) in that cluster.

Thus for each stable match in a firm, the worker  $y \in (b^n, b^{n-1}]$  is at least as good as

or strictly better than going out for another search:  $(1 - \theta)F(a^n, y) > \delta EU_y(\sigma_y, \sigma_x)$ . The expected payoff from a stable match for this worker is strictly better than the expected value of search:

$$(1 - \theta) \frac{\int_{a^n}^{a^{n-1}} F(x, y)g(x)dx}{\int_{a^n}^{a^{n-1}} g(x)dx} > \delta EU_y(\sigma_y, \sigma_x)$$

This makes this worker unwilling to leave the current match, or current firm. Similarly for all the managers. This in turn gives the firms some monopsony power on their employees' human capital.

Due to this reason, firms are willing to provide some extent of general skill trainings for their current employees, even though these skills are general across firms and firms face the risk that their employees may leave after acquiring these skills.

For each firm, the optimal strategy is to offer cluster-specific skill training programs to its employees. Within each cluster, firms train those low-skill agents to improve their skill levels upto the level of the best agents in that cluster. In such a way, within each cluster, agents are getting acceptable better partners through this training program without jumping into an upper cluster and rejecting the current partner. Additionally, due to the two-sided match problem and the team-production, firms are more willing to provide group training for each match so that skill levels of both partners grow together. This strategy maximizes the final output and also reduces the probability of separation when two partners' qualities diverge too much.

As we can see from the above analysis, task-specific human capital can generate firm-specificity in this team-production approach. If we think of different occupations as weighted bundles of different tasks, then each worker with certain bundle of (task-specific) skills has a optimal choice of occupation that maximizes the total payoff of his skill set. Any separation from his current optimal choice will results in a loss in his skill returns. In this sense, task-specific human capital acts like occupation-specific. Analogously for the industry-specificity of human capital. In the end, to what extent is human capital specific is an empirical question to be answered with proper data in the future.

### 3.2.2 Human Capital Investment

Now I allow human capital to be endogenously determined by agents' human capital investment decisions, and investigate its return. A new microfoundation for the increasing returns in human capital accumulation is presented.

Consider the human capital investment decisions of worker  $y$  in the subinterval  $(b^n, b^{n-1}]$  and manager  $x$  in the subinterval  $(a^n, a^{n-1}]$ . Given the search equilibrium, the expected utility for worker  $y$  is given by:

$$EU_y = (1 - \theta)f_2(y)\frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{a^n}^{a^{n-1}} f_1(x)g(x)dx, \quad (3.2.1)$$

and the expected utility for the manager  $x$  is given by:

$$EU_x = \theta f_1(x)\frac{M(\lambda^m, \lambda^w)}{\lambda^m} \int_{b^n}^{b^{n-1}} f_2(y)h(y)dy, \quad (3.2.2)$$

where  $f_1$  and  $f_2$  are strictly concave functions.

If the cost of human capital investment is  $c$  per unit for every agent in this economy, then each worker and manager will choose the optimal amount of investment to maximize their expected utility that are given above.<sup>12</sup> For worker  $y$ , the first order condition is

$$f_2'(y)(1 - \theta)\frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{a^n}^{a^{n-1}} f_1(x)g(x)dx = c;$$

And for manager  $x$ , the first order condition is

$$f_1'(x)\theta\frac{M(\lambda^m, \lambda^w)}{\lambda^m} \int_{b^n}^{b^{n-1}} f_2(y)h(y)dy = c.$$

As we can see, the individual investment decision will not take into account any other agent's investment decisions. However, due to the team-production organization, each worker's marginal output of human capital investment depends on the quality of all

<sup>12</sup> Now we are restrict our consideration to the situation that the human capital accumulation does not change the cluster that each agent belongs to. The cluster jump through investment will be discussed later in this subsection.

managers in the same cluster. The human capital investment decision of each manager (worker) has some positive externality on other workers (managers) in the same cluster. As a result, a small increase in the human capital investments of all agents would make everyone better off. In this sense, there exist social increasing returns in human capital accumulations.

Now let us consider the case when human capital accumulation changes the cluster one belongs to. If a small human capital investment by worker  $y \in (b^n, b^{n-1}]$  moves him out of his current cluster, into an upper cluster  $y' \in (b^{n-1}, b^{n-2}]$ , his expected utility changes into

$$EU_{y'} = (1 - \theta)f_2(y') \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{a^{n-1}}^{a^{n-2}} f_1(x)g(x)dx.$$

The actual return to this investment comes from two parts. The first is the increase of  $f_2$  value; The second part is the increase in the quality of his partner-manager from the upper cluster and the increase in the probability of stable match in the new cluster. Thus even when function  $f_2$  is strictly concave, if the increase from the second part is large enough, the total return to human capital investment may feature increasing returns to scale.

To summarize, the above two cases both in some sense provide a foundation for the increasing returns to human capital accumulation.

### 3.3 *Testable Empirical Implications*

In the previous section I have presented the team-production approach based on the two-sided search problem, and also discussed its rich theoretical implications on human capital specificity, worker turnover and the returns in human capital accumulation. There are also many testable empirical implications, which can lead to promising empirical projects that can help us to tell how the current model and alternative theories in the literature work in the real economy. I list some of these empirical implications as below.

1. *Correlation between Wages and Turnover Rates* This paper has shown that, given random matching with labor market search frictions, high-quality is associated with

high probability of forming stable matches. This can be used to explain the negative correlation between wages and turnover rates. Now if the labor market frictions decrease, either searching costs shrink or information incompleteness decreases, agents become more picky, and in the two-sided search equilibrium the cluster sizes all shrink. In the extreme case, when search is costless, as in the classical marriage matching problem the perfect positively assortative matching will be the new equilibrium. In that case, this correlation between agent quality and probability of achieving a stable match disappears. So does the negative correlation between the wages and turnover rates.

2. *Endogenous Market Thickness* Lazear (2009) defines the market thickness as the number of offers worker receives for a given amount of search effort. Here I can also define similarly a market thickness, which endogenously depends on the quality of agents. As we can see from the two-sided search equilibrium, high-quality agents receives more acceptance for any given amount of search effort. Thus the market for high-quality agents is endogenously thicker. This implication may be directly tested with data on agent quality, search costs proxies and offer frequencies.
3. *Wage dispersion for different clusters* Following from similar argument as above. Top class high-quality agents not only receive more acceptance, but also get a more diverse pool of partner quality. Thus the wage dispersions within clusters decrease with  $n$ , the ranking of clusters.
4. *Wage dispersion within categories* The wage dispersion within each category of agents is related with the number of clusters. As the search friction shrinks, the search equilibrium approaches perfectly positive assortative matching, cluster number increases, the wage dispersion of the whole category also increases.
5. *Firm Training* This paper has shown that with team-production firms are willing to train their employees even when the skills are general across firms. For each matched agent, his current payoff is at least as good as the expected value of continuing search.

In particular, almost for all employees in the firms, the payoff is higher than the expected value of search. If he leaves the current firm, he is almost certainly to be worse off. Thus current employees' human capital acts like specific to the current firms. In addition, firms are more willing to provide group training or coordinated individual training programs, in order to improve the specialization and coordination between their employees. These programs not only improve the employees' productivity but also reduce their separation probability.

6. *The extent of specificity by cluster* From the search equilibrium we see that agents' expected value of search in each cluster equals the payoff from matching with a partner of the lowest quality from the same cluster. Due to the fact that higher clusters have larger sizes, when quality distributions are well-distributed (e.g. uniformly), the difference between the payoff from expected stable matching in that cluster and the expected payoff from searching is larger for higher clusters. In other words, agents in higher clusters are more specific to their current matches. It looks like high-quality agents are more specialized or specific to current firms/matches/occupations/industries as many empirical exercises have found.
7. *Team and Specialization* The two-sided search problem investigated in this paper can be generalized into a multilateral search case. With increased team size, i.e. extent of specialization in production, it becomes even harder for a given worker to find an acceptable crew outside of the current firm. Firms are more willing to provide general skill training in this case. Skills are now general across firms, but more narrowly specialized in certain task(s). This implication can be tested with data on trainings and sizes of production units across industries.
8. *Occupation- and Industry-Specificity* As one can see from this paper and the literature, it is actually hard to clarify the specificity of skills both theoretically and empirically. By assuming only task-specific human capital, this model endogenously generates a form of firm-specificity with team-production. The model can also gen-

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erate occupation-specificity by assuming that occupations are just weighted bundles of different tasks. Within different occupations, different tasks are demanded with different shares. Thus every agent with a particular bundle of skills has his optimal occupation choice, which makes his skill bundle occupation-specific. Analogously the industry-specificity can be generated. To validate this microfoundation of occupation and industry specificity, it requires more detailed data and a rigorous empirical investigation.

### 3.4 *Conclusion*

This paper answers to the call in the literature for investigations on the specificity and returns of human capital, and presents a team-production model based on the two-sided search problem. It is shown that this model generate a form of firm-specificity even when skills are intrinsically general across firms. This is due to the team-production organization, a stable matched team is unwilling to separate unless the shock to the current match is big enough. It works as if agents' skills are specific to the current firms(matches). This result has rich implication on firm trainings as discussed above. In the equilibrium of this two-sided search problem, agents are characterized by different clusters where agents from the same cluster adopt the same search strategy and form stable match with each other. From this equilibrium, it is naturally followed that high-quality agents can form stable match more easily given that meeting is random. This results in a negative correlation between the wages and turnover rates as empirically found.

In this team-production approach, human capital accumulation may feature increasing returns to scale. Each individual's investment decision has positive externality on the return of all his potential partners' human capital. Thus a small increase in all agents' human capital may make all agents better off. Additionally, for each individual, human capital accumulation may also have increasing returns if his increase in human capital moves him up to an upper level cluster, so that he will have a higher probability of stable matching and also a partner with better quality.

Several interesting empirical implications are also listed in the paper. Some of them already have empirical support from the literature, others still need future empirical investigation.

Finally, the current team-production approach may be extended in many ways. One way is to a multi-literal search problem with larger team size, which is discussed briefly in the last section. Another way is to model the behavior of firms. Notice that, in the current model, firms are just stable matches or a group of matches. The market for firms are competitive, there is no profit for firms as a third party other than the two partners on each team. A more realistic case will be thinking firms are intermediate matchmakers. Within each firm, there is a group of workers and managers. As an employer, each firm is responsible for assigning the matches between its workers and managers. Different firms may differ in their pool of employees, and also their matching technology. Large firms may attract more high-quality employees and form better teams than smaller firms. This may generate a size-wage effect across firms. All these interesting extensions will be pursued in my future research.

### 3.5 Appendix

#### 3.5.1 Proof of Theorem 2.2

I start with two simple lemmas on the equilibrium search strategy of worker  $y$ .

**Lemma 3.1.** *In equilibrium, for any worker  $y$ , the set of manager he accepts  $X(y)$  is an interval of the form  $(x(y), 1]$ .*

*Proof.* Obvious. If worker  $y$  accepts manager  $x$ , he will accept any manager with higher quality  $x' > x$ . □

**Lemma 3.2.** *The function  $x(\cdot)$  defining the highest quality that worker  $y$  rejects is nondecreasing in  $y$ .*

*Proof.* Obvious. If manager  $x$  is not accepted by worker  $y$ , she will not be accepted by any

worker with higher quality  $y' > y$ . So  $x(y')$  can not be lower than  $x(y)$ . Thus function  $x(\cdot)$  is nondecreasing.  $\square$

*Proof of THEOREM 2.2.* From Lemma 5.1, we know that the set of manager accepted by worker  $y$  is an interval  $(x(y), 1]$ . By Lemma 5.2 we also know that the set of manager accepting worker  $y$  is an interval of the form  $[0, \xi(y)]$ . The equilibrium expected utility of worker  $y$   $V(y)$  is given by:

$$\begin{aligned} V(y) &= \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} (1 - \theta)F(x, y)g(x)dx \\ &+ \delta V(y) \left[ 1 - \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} g(x)dx \right] \end{aligned} \quad (3.5.1)$$

The search problem faced by worker  $y$  thus can be written as the follows:

$$\max V(y) = \frac{\frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} (1 - \theta)F(x, y)g(x)dx}{1 - \delta \left[ 1 - \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} g(x)dx \right]} \quad (3.5.2)$$

Taking first-order condition with respect to  $x(y)$ ,

$$\begin{aligned} &-(1 - \theta)F(x(y), y)g(x(y)) \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \left\{ 1 - \delta \left[ 1 - \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} g(x)dx \right] \right\} \\ &+ \delta \left[ \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \right]^2 g(x(y)) \int_{x(y)}^{\xi(y)} (1 - \theta)F(x, y)g(x)dx = 0 \end{aligned}$$

Use the multiplicative separability of  $F(x, y) = f_1(x)f_2(y)$ , the above first-order condition can be written as:

$$f_1(x(y))(1 - \delta) = \delta \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(y)}^{\xi(y)} [f_1(x) - f_1(x(y))]g(x)dx \quad (3.5.3)$$

Observe that the left-hand side of Equation (5.3) is increasing in  $x(y)$ , rising from 0 to  $f_1(\xi(y))(1 - \delta)$ . On the hand, the right-hand side of Equation (5.3) is decreasing in  $x(y)$ ,

falling from

$$\delta \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_0^{\xi(y)} [f_1(x) - f_1(0)] g(x) dx$$

to 0. Hence there exists a unique solution to this equation in the interval  $[0, \xi(y)]$ .

Now consider the best worker with  $y = 1$ . All managers accept him, and the highest-quality manager he rejects  $x(1)$  is the solution to

$$f_1(x(1))(1 - \delta) = \delta \frac{M(\lambda^m, \lambda^w)}{\lambda^w} \int_{x(1)}^1 [f_1(x) - f_1(x(1))] g(x) dx$$

Hence, the existence of frictions on the labor market implies that the best type worker accepts to match with any manager  $x$ , with  $x(1) < x \leq 1$ . Then all managers  $x \in (x(1), 1]$  are accepted by all the workers and face the same search problem as the best worker. They should behave identically, and the lowest woman they accept  $y(1)$  is the solution to

$$f_2(y(1))(1 - \delta) = \delta \frac{M(\lambda^m, \lambda^w)}{\lambda^m} \int_{y(1)}^1 [f_2(y) - f_2(y(1))] g(x) dx$$

Thus we obtain the two top clusters  $(x(1), 1]$  and  $(y(1), 1]$  of managers and workers who all adopt the same strategy and end up matching with each other. I redefine these clusters are  $I^1 = (a^1, a^0]$  and  $J^1 = (b^1, b^0]$ . Then consider the best manager and worker left on the market  $x(1)$  and  $y(1)$ . A recursive application of the previous argument leads to the formation of the collection of clusters  $I^n$  and  $J^n$ .  $\square$

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