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Abstract

This paper provides an analysis of what may be seen as a generalized Smithian Theorem that the division of labor is limited by uncertainties, knowledge, and transaction/coordination costs (as well as the extent of the market). The interplay between knowledge and uncertainty on the one hand and progressive specialization on the other, and the implication of inter-occupational difference in human capital investments for the division of labor are further analyzed. (*JEL*: D81, D51, O12)

Keywords: Division of labor; Transaction uncertainty; Human capital; Transaction/coordination costs; Risk aversion.

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1. Introduction

It has long been known to economists (often referred to as Adam Smith's Theorem) that increasing returns to specialization imply economies of the division of labor and that the division of labor is limited by the extent of the market. The recent two decades have seen a revival of interest in Smith's theory of the division of labor, which has been largely taken for granted and effectively ignored for quite long since Allyn Young's (1928) celebrated piece. Drawing on the literature of human capital, Rosen (1983) and Barzel and Yu (1984) explore the ways in which the utilization rate of activity-specific human capital investment may promote specialization. Becker and Murphy (1992) argue that the division of labor is limited not only by the Smithian transport-constrained market extent, but also by coordination costs and knowledge. To introduce human capital, and knowledge in general, into the theory of the division of labor certainly provides an important insight into economic progress that is associated with increased specialization. Market interaction among individuals' decentralized decisions of specialization, however, is largely ignored in each of the above studies.

On the other hand, Yang and Ng (1993) develop a general equilibrium framework to explore the implications of transaction costs for the social division of labor, and apply their theory to an impressively great range of economics issues.

Lio (1998) further introduces trading uncertainty into the Yang-Ng framework to analyze the positive effect of insurance upon per capita income via promoting specialization and the division of labor.[1] But knowledge is simply absent in both Yang and Ng's (1993) and Lio's (1998) analyses.

The purpose of this paper is twofold. First, we develop a model which accommodates knowledge, transaction uncertainty, transaction/coordination costs and risk aversion to investigate their effects on the division of labor in a unified framework. The rather complicated interplay among them is also analyzed. Secondly, different from Lio's treatment of uncertainty in transactions wherein what really matters is the expected transaction efficiency rather than transaction uncertainty *per se*, we explicitly explore the implication of transaction uncertainty, and the stability of the trading network in general, for the division of labor. In doing so, we draw on an interesting result due to Rothschild and Stiglitz (1970) on the measure of risk. We also study the effect of knowledge and transaction uncertainty on the inter-occupational difference in wage rates, specialization patterns and trade dependence.

We show that uncertainty and knowledge both profoundly influence the choice of specialization patterns. Increased knowledge promotes complexity and productivity of skills, yet at the cost of increased occupation-specific human capital

[1] Note Yang and Wills (1990) also draw on the notion of transaction risk to develop a theory of property rights. In fact, their model turns out to be a special case of Lio (1998).

investments. Consequently, specialization is further promoted at the expense of greater risk of transaction/coordination failure. Transaction uncertainty and risk aversion on the other hand discourages specialization to safeguard oneself from risk associated with trading activities. Occupations that require a greater fixed investment of human capital will be better paid than the others not only because of the longer period of directly unproductive "apprenticeship", but also because of greater uncertainty incurred, as being more specialized necessarily implies being more deeply "embedded" into the more or less risky network of trade and the division of labor. As a consequence, the wage rate gap between the human capital intensive occupations and others increases with transaction uncertainty.

The paper proceeds as follows. The next section develops a simple (symmetric) model of specialization based on fixed element of activity-specific human capital investment. The model incorporates transaction costs and uncertainty as well. The effects of knowledge, transaction costs, uncertainty and risk aversion are analyzed in some details. Particular attention is given to the role played by knowledge and uncertainty and the interplay between them. Section 3 relaxes the symmetry of the model to investigate inter-occupational disparities, in terms of specialization patters and wage rates, due to increased knowledge, increased human capital investment, and increased uncertainty. Section 4 concludes.

2. An equilibrium model

2.1 The setting

We consider an economy with many intrinsically identical consumer-producers and m consumption goods/services. But the agents may choose between different occupations providing different commodities in the market. As is repeatedly emphasized in Smith (1776), *ex post* specializations and hence difference in skills among people of different occupations are more likely the consequences of, rather than the stimuli to, the division of labor. The assumption of the intrinsic identity of agents is made in this paper, as elsewhere (Rosen 1983, Barzel and Yu 1984, Becker and Murphy 1992, Yang and Ng 1993, Lio 1998, Sun and Lio forthcoming), to further exploit Smith's notion of the division of labor, which sharply differs from Ricardo's that is based on intrinsic differences among people/countries. As in Lio (1998), each consumption good is a necessity and, to simplify the analysis without losing any insight, a Cobb-Douglas utility function is assumed,

$$u(.) = (\prod_{i=1}^{m} x_i)^{1/\rho} \qquad (1)$$

where $\rho > m$ is required by the concavity of the utility function.

Each agent is endowed with L hours of labor, which she can allocate among m activities for producing the consumption goods. However, to acquire the occupational-specific skill she needs to invest some "training" time, which even casual observation would suggest increases with the general knowledge available. The necessary training time for acquiring the occupation-specific human capital is assumed to be the same across production of all the commodities, $C_i(H) = C(H)$, $i = 1,...,m$, where H is the amount of general knowledge, $C' > 0$. On the other hand, the productivity of each efficient working hour, q_i, is augmented by the general knowledge, $q_i = q(H)$, $i = 1,...,m$, $q' > 0$.[2] Thus, for L_i hours allocated to producing goods i, the "training" time is $C(H)$, and the "working" time $L_i - C(H)$, of which the productivity is $q(H)$. Hence the production function

$$f(L_i) = q(H)(L_i - C(H)) \qquad (2)$$

It might be thought that one should be completely specialized in one activity to exploit to the full the economies to specialization due to the fixed training investment. But to be specialized in one or few activities necessarily means trading what one produces by herself for other goods/services and thereby transaction/coordination costs are necessarily incurred (Becker and Murphy 1992, Yang and Ng 1993). The tradeoff in most cases would not result in complete specialization. For the sake of exposition, transaction costs are assumed to be borne

[2] The double effects of growth in knowledge on production are articulated in Rosen (1983).

by buyers alone throughout the paper to simplify the technical analysis. Note this assumption is not far away from reality since each buyer (of one good or service) is also a seller (of another) in our model due to her budget balance constraint. A proportion of what is purchased from the market disappears and therefore when purchasing y units of good i from the market, the amount the agent actually obtains is $k_i y$, $0 \le k_i < 1$.[3] The greater the realized value of k_i, the more efficient the transaction is. For any given price signal, $(p_1,...,p_m)$, the agent optimizes upon her time allocation between training and production and her trading plan. But one most noticeable feature of the market transaction is uncertainty, which can't be foreseen or well-contracted. This is precisely what truly underlines the "transaction costs". To avoid the epistemological difficulties in dealing with the Knightian uncertainty, we will focus on a rather simple situation to keep the model tractable: the agent has a prior probability distribution of possible states of the market transaction, presumably formed from previous experience, or from advertisements, newspapers, neighbours or whatever. Formally, the trading efficiency parameter k_i ($i = 1,...,m$) are random variables, which are assumed to be independently identically

[3] Dahlman (1979) further specifies the transaction costs into three categories: information costs, bargaining, negotiation and decision costs, and policing and enforcement costs. But for our purpose, we rather loosely use the terms transaction costs and trading costs synonymously.

distributed (i.i.d.), with accumulation function $F(.)$.[4] As such, the agent would optimize her von-Neumann-Morgenstern expected utility via time allocation between training and working and her trade plan. The only constraints are the budget balance and total available time.

2.2 Equilibrium

As to the individual decision on time allocation and trade plan, the technical assumption that all the trading costs are borne by buyers and the linear production functions immediately imply that each agent can always achieve her maximal expected utility by selling at most one type of product or service, since otherwise she would gain no less expected income from selling by re-allocating time for production of two or more sold products and selling only one good with all the self-provided consumption being unchanged. In other words, she is specialized in one occupation in the trading network to exploit the economies to utilization of the fixed human capital investment. Similar arguments suggest that one would not buy and self-provide the same goods or service.[5]

In equilibrium, the intrinsically identical agents would have ex post comparative advantages since they choose different occupations in the division of

[4] In Lio (1998), the rather simple two-point distribution is considered without incorporating knowledge and hence the interplay between knowledge, specialization and uncertainty. See below for more discussion on this.

[5] Wen (1998) generalizes Yang and Ng (1993)'s proof for this result, often referred to as Wen Theorem, yet in the absence of uncertainty.

labor, but the expected utilities of different professionals should be the same (otherwise people will shift from a "bad" occupation to a "good" one in terms of expected utilities). The symmetry of our model requires the relative price of different goods/services to be unitary. Thus, the analysis of the endogenous prices is rather a trivial exercise. (An asymmetric model wherein the relative price issue is not a trivial one is proposed in the next section, to address the inter-sector income distribution that changes with the increasing amount of knowledge). The equilibrium *structure* of the division of labor, however is quite different, and, as shown below, would naturally depend on, or, as the literature on the division of labor conventionally puts it, is "limited" by, many factors, among which the most crucial are "the extent of the market", the general knowledge, trading costs, how risk averse agents might be, and in particular how stable and predictable transaction conditions may be.

Formally, the von-Neumann-Morgenstern utility function for the agent of occupation i is,

$$Eu(.) = E[(f(L_i) - x)\prod_j f(L_j)\prod_s (k_s y_s)]^{1/\rho} \qquad (3)$$

subject to the time and budget constraints $L_i + \sum_j L_j \le L$ and $\sum_s p_s y_s \le p_i x$ as well as the nonnegative-ness constraint of decision variables. (any j in (3) refers to one self-provided good, household for instance; s refers to one good purchased, x is

the amount sold of good i and y_s the amount purchased of good s). The symmetry of the model considerably simplifies the decision problem (3) (noting the relative price between any pair of goods is one due to the equalization of expected utilities), and it is easy to obtain the maximal expected utility,

$$EU = [q(H)/m]^{m/\rho}[L-(m-n^*+1)C(H)]^{m/\rho}[E(k^{1/\rho})]^{n^*-1} \qquad (4)$$

where the number of traded commodities

$$n^* = m+1-\frac{L}{C(H)}-\frac{m}{\rho \ln[E(k^{1/\rho})]} \qquad (5)$$

The time the agent allocates to her very occupation, which we shall refer to as her specialization level, $l^* = n^*\frac{L-(m-n^*+1)C(H)}{m}+C(H)$.

2.3 Knowledge, transaction efficiency and the extent of the market

Niels Bohr once commented on two types of minds in his physics profession: a Philosopher starts knowing something about some things, gets to know less and less about more and more, and an Expert also starts knowing something about some things but gets to know more and more about less and less. What's behind Bohr's concern is that scientists or academics in general come to be specialized in a narrower and narrower field as knowledge increases.[6] The entry barrier to each occupation (the indivisible human capital investment in the profession) increases

[6] But he further remarks immediately that eventually there is no difference between them, since the former gets to know nothing about everything but the latter knows everything about nothing !

and people have even stronger incentives to be specialized in a narrow range of activities as a greater amount of knowledge becomes available, even if the cognitive capability for grasping a great deal of knowledge as the latter "explodes" is not a serious problem. To exploit the economies to increased human capital investment, the utilization rate must be increased as well, and as a consequence, people would be more specialized and "embed" themselves more deeply into the thus enlarged network of trade and division of labor. Indeed, we obtain from Eq. (5),

$$\frac{\partial n^*}{\partial H} = \frac{LC'(II)}{(C(II))^2} > 0 \qquad (6)$$

Becker and Murphy (1992) forcefully argue for the significant effect of general knowledge upon the division of labor using an aggregate benefit-cost model. But the increasing human capital to be acquired for a particular professional career due to a greater amount of available knowledge, a key issue in understanding the narrowness of each individual in modern economies, is missed in their analysis. Nonetheless, the examples Becker and Murphy (p.145) draw from medical, engineering and economics on the finer specialization largely driven by increasing knowledge are quite illustrative.

Other things being the same, if the trading condition is improved, there will be incentives for the agent to be more specialized in a narrow range of productive

activities since the (transaction) costs in doing so would be correspondingly reduced and hence the market size for each individual enlarged. The social division of labor is thereby enhanced. Many factors, for instance, transportation networks, well-established routines in doing business and the legal system, have a profound influence on the transaction efficiency. Note the "transaction" may be interpreted as including coordination, for in a large network of the division of labor with many differentiated specialists one has to communicate and coordinate with others by trading ideas and information by and large.[7]

In our rather simple model with a fixed variety of goods, the division of labor reaches its limit once $n^* = m$. Apparently, if the population size in the economy, N, is less than the potential number of traded goods (occupations), m, the economies from division of labor will be exhausted even earlier. Moreover, even if the number of actually traded goods is far less than m, the division of labor may also be limited by the population. However, one must be cautious to not confuse the extent of the market with the population size *per se*, though the latter often has a significant implication for the former. As Allyn Young (1928, pp. 532-3) long ago observed, "Taking a country's economic endowment as given, the most important single factor in determining the effectiveness of its industry appears to be

[7] It is true that increased knowledge and technological change do have influence on the trading/ coordination efficiency, parameter k in our model, and that it is easy to show that the positive effect of knowledge on the division of labor would be even greater provided that $\partial k / \partial H > 0$, which seems to hold in most cases.

the size of the market. But just what constitutes a large market? Not area or population alone, but buying power, the capacity to absorb a large annual output of goods. This trite observation, however, at once suggests another equally trite, namely, that capacity to buy depends upon capacity to produce." Young (p.540) put it even more sharply in concluding his celebrated Presidential Address before the section of Economic Science and Statistics of the British Association for the Advancement of Science, "The division of labor depends upon the extent of the market, but the extent of the market also depends upon the division of labor." For our purpose here, however, it seems enough to point out that the market size and the division of labor are limited by knowledge and transaction conditions, with the latter ultimately resulting from institutional arrangements (e.g., the legal system, the extent of state opportunism and so on) and infrastructure. See Sun and Lio (forthcoming) for a systematic investigation on Young's theory of the division of labor.

2.4 Transaction uncertainty, risk aversion and specialization

Anyone who is specialized in a narrow range of activities has to trade with others, and consequently faces transaction uncertainty and the associated costs incurred. One would therefore expect that the more risk averse the agent is, the less specialized she will be. Note that the parameter ρ in our model characterizes the

concavity of the utility function and thus can be used as a measure of risk aversion, we obtain from Eq. (5) (a rigorous analysis is found in Appendix 1)

$$\frac{\partial n^*}{\partial \rho} < 0 \qquad (7)$$

One interesting insight that maybe gained from the above is that relatively more conservative (more risk averse) communities may miss out on specialization-driven economic progress in avoiding the risk of transaction/coordination failure involved, though the expected utility is maximized regardless of the degree of risk aversion. [8]

Another issue of particular interest is the effect of stability and foreseeability of transaction on the division of labor and utility. Note in our model the transaction efficiency parameters k_i, $i = 1,...,m$, are i.i.d. random variables within the interval between zero and one. To analyze the effect of transaction uncertainty on the division of labor, we consider two density functions of the transaction efficiency parameter k, $f_1(k)$ and $f_2(k)$. The two distributions have the same mean, but the transaction condition under distribution two is less stable, or in other words, more risky, than under distribution one in the sense that f_2 can be obtained by taking some probability weights around the center of f_1 and adding to both tails of f_1 with the mean preserved. As analyzed by Rothschild and Stiglitz (1970), distribution two can also be obtained by adding a noise term of zero mean to distribution one,

[8] But one should be cautious of interpreting this observation to refer to the economic effect of "cultures"; for there are a number of other factors, for instance, insurance, which maybe used as a safeguard, to some extent, against uncertainty to promote specialization (Lio 1998).

and therefore the former, intuitively speaking, is more uncertain than the latter. Since $\rho > m > 1$, $h(k) \equiv k^{1/\rho}$ can be *formally* seen as a *concave* utility function (of k). Thus, by the Equivalence Theorem of Rothschild and Stiglitz (1970, Theorem 2, p. 237), $E_2(k^{1/\rho}) < E_1(k^{1/\rho})$, where $E_i(k^{1/\rho})$ is the expected value of $k^{1/\rho}$ under distribution i, $i = 1,2$. But from Eq. (5), n^* increases with $E(k^{1/\rho})$. As a consequence, $n_1^* > n_2^*$. That is, instability in transactions may severely limit the division of labor. A reliable legal system to facilitate the enforcement of contracts made is required for a well-developed specialization system. Furthermore, the envelop theorem immediately implies from (4) that the expected utility under transaction system 1 is higher than that under transaction system 2. As such, our analysis lends even stronger support to an efficient market system, precisely on which the complicated network of division of labor with differentiated specialization patters is based. Without an efficient market-oriented legal system and accompanying institutional infrastructure, which facilitate and maintain market trading activities, economic progress that is based on the progressive division of labor is simply impossible. Problems faced by troubled transition economies appear to be likely with a legal system that is conducive to the functioning of the market economy rather than production sectors. Svejnar (2002), in assessing the strategies and performance of the transition economies, highlights the significant role played by what he terms as Type II reforms, "Type II reforms involved the development

and enforcement of laws, regulations and institutions that would ensure a successful market-oriented economy" (p.5). Unfortunately, few transition economies have carried out Type II reforms. Our analysis of the profound influence upon the division of labor of a reliable transaction system may thus shed new lights on why and how the transition has proved to be such a tremendously challenging and long-lasting process.[9]

3. Knowledge, uncertainty, asymmetry in human capital investments and wage gap

We relax in this section the assumption that requires the *same* amount of indivisible human capital investment ("training" time) in the production of each product, in order to investigate the effect of differences in human-capital-intensity among activities on the division of labor. To avoid algebraic complication, only one profession is assumed to be more human-capital intensive than the others, $C_h(H) > C_1(H) = ... = C_{h-1}(H) = C_{h+1}(H) = ... = C_m(H) = C_{-h}(H)$ for any amount of general knowledge H. The productivity of each working hour in each activity, for

[9] Svejnar (2002, p.7) observes, "the lack of a market-oriented legal structure appears to have been the Achilles' heel of the first dozen years of transition. Many policy makers underestimated the importance of a well functioning legal system or believed too readily that free markets would take care of any major problems." Roland (2002) also argues from a different perspective that economists often go astray in analyzing what's really going on and what really matters in the transition, by largely ignoring the rather deep institutional transformations underlying the transition to market economies. Also see Posner (1998) for an analysis of the profound implication of legal infrastructure protecting contract and property rights for economic prosperity.

simplicity, remains the same as in the symmetric model.[10] As analyzed in subsection 2.2, each agent will choose only one occupation and supply that particular commodity. Equalization of expected utilities across occupations implies price equalization among the less knowledge intensive professions, denoted as p_{-h}. Note p_{-h} may also be seen as the (uniform) wage rate for these occupations. As such, there is no difference in their specialization patterns except differences in particular occupations. Since those who choose occupation h invest more time on "training" (apprenticeship or schooling, for example) and hence less time for effective working, their specialization patterns and wage rates would be expected to be different from others. Denote by p_h the price of their product or service, and let $p = p_h / p_{-h}$ be the price ratio. The expected utilities of occupations h and others are then respectively as follows

$$EU_h = [q(H)/m]^{m/\rho}[L-(m-n_h^*)C(H)-C_h(H)]^{m/\rho}[E(k^{1/\rho})]^{n_h^*-1}\, p^{(n_h^*-1)/\rho}$$

$$\text{where } n_h^* = m + \frac{C_h(H)}{C(H)} - \frac{L}{C(H)} - \frac{m}{\rho \ln[p^{1/\rho}E(k^{1/\rho})]} \qquad (8)$$

and $EU_{-h} = [q(H)/m]^{m/\rho}[L-(m-n_{-h}^*)C(H)-C(H)]^{m/\rho}[E(k^{1/\rho})]^{n^*_{-h}-1}/p$

$$\text{where } n_{-h}^* = m+1-\frac{L}{C(H)} - \frac{m}{\rho \ln[E(k^{1/\rho})]} \qquad (9)$$

[10] Assuming that the productivity improvement by increased knowledge is the same across activities is certainly unrealistic. But we here focus only on the heterogeneity of fixed elements of human investment, and contend that more significant effect of increased knowledge upon the productivity of the human capital intensive profession than in other professions, as the case in overwhelmingly mast cases, would even further enlarge the wage gap.

In equilibrium, the expected utilities are the same across occupations. As a consequence, the occupation of higher human capital intensity requires a wider range of trading goods; it can be further shown that the gap in specialization levels (time allocated to the occupation one chooses) between the occupation *h* and others not only arises from the inter-activity difference in human capital investment, but is also compounded by the increased trade dependence and the wage gap in equilibrium between the human capital intensive occupation and others. (See Appendix 2 for analyses.) The specialization gap becomes even larger as a consequence of increased general knowledge, H, which implies a higher trade dependence and human capital investments in all activities, provided that the increased knowledge leads to an even higher human-capital-intensity in occupation h, a plausible assumption in most cases. The competition in the knowledge-intensive professions gets correspondingly even greater.

The wage ratio, obtained from equalization of expected utilities between occupation *h* and others, could be shown, as in Appendix 2, to be dependent upon many factors, $w = p = p(C_h, C, E(k^{1/\rho}), m, \rho)$. Thus, the endogenous price is not a trivial issue any more in this asymmetric case. Two observations seem to deserve particular attention. First, we have, $\partial p / \partial C_h(H) > 0$. Intuitively, if the fixed investment in any other occupation remains unchanged, increasing the training hours in the human capital intensive occupation alone necessarily implies less

effective working hours left and hence the relative wage rate compared to others has to be increased in order to compensate for the longer time invested on directly unproductive "learning". Naturally, $\partial p / \partial C(H) < 0$. Since the increased knowledge may increase fixed elements of investment costs in both the human capital intensive occupation and other ones, the effect of growth in general knowledge upon the wage gap would depend on which effect predominates. As shown in Appendix 2, the wage ratio, $w = p$, being greater than unity, becomes even larger if the growth in knowledge generates a no less influence on the required human investment in the occupation h than in other ones; formerly, $\partial p / \partial H > 0$ when $\eta_h \geq \eta_{-h}$, where $\eta_h(\eta_{-h})$ is the knowledge elasticity of fixed human capital investment in occupation h (other ones). Given that one has to invest many years studying in medical and law schools to be qualified as a physician or attorney, it would not be a surprise that the wage rates for these professions almost always remain remarkably high.

Secondly, presumably more interesting, the relative wage rate increases with trading uncertainty, since $\partial p / \partial (Ek^{1/\rho}) < 0$ (note a more uncertain trading system is associated with a smaller value of $E(k^{1/\rho})$, be the mean trading efficient preserved, as is indicated by the analysis on the latter in subsection 2.4), . Namely, if the transaction becomes a bit more unpredictable as the trading network becomes more complicated, the wage rate of the occupation that requires long term schooling

investment will increase, *partly* for compensation of the higher trade dependence of those who choose this occupation. A farmer may provide quite a fraction of what he may consume, the production of which does not require too much indivisible human capital investment. But it usually requires quite some years to be a professional in the R&D sector, whose most time is invested in a prètty narrow field and whose consumption can hardly be self-provided, even in a much less proportion. The latter is therefore more vulnerable to any shocks on the market trading system. For this reason *alone*, they are expected to be paid higher.

4. Concluding remarks

This article addresses effects of knowledge and uncertainty in transactions on the division of labor, by integrating two research lines mentioned in the introduction and drawing particular attention to the influence of transaction uncertainty and risk aversion on the choice of specialization patterns. Transaction uncertainty alone has an important influence on the division of labor. A greater amount of knowledge is likely to promote specialization and the division of labor. To be specialized in a narrow range of activities implies higher trade dependence and greater transaction costs incurred. But uncertainty is a crucial element of the "transaction costs". As such, the benefits that arise from improved division of labor due to development of new knowledge may be less significant than maybe thought. The division of labor

is limited by uncertainty, among other well recognized factors. Insurance may help alleviate the problem. But some contingencies may be never covered by any comprehensive contract. A stably functioning market-oriented legal system, efficient routines in doing business and even trust facilitating social norms may have even greater influence on economic progress via promoting the division of labor than may be conventionally thought.

One question of practical relevance naturally emerges from the analysis of limiting factors of the division of labor: which one predominates? The answer appears to really depend on the economy in question. Presumably, some basic infrastructure for transportation and telecommunication is the most needed for underdeveloped countries, wherein the transaction costs are badly high. For many transition economies, as mentioned above, a stably functioning market-oriented legal system seems to be the priority on the development agenda, while for most developed OECD economies the main driving force for further division of labor is no doubt development of new knowledge. However, we mean in no sense to understate the rather complicated intertwining among the above factors.

To be sure, only *transaction* related uncertainty is considered in our analysis. Progressive specialization is often associated with other kinds of uncertainties; for example, if one is very specialized in some narrow area, the risk of failure in finding a job may be considerably higher than otherwise. Nor is uncertainty in the

specialized production process considered. If these were taken into account, the effect of uncertainty as a limiting force of specialization would be even greater. Largely motivated to highlight the often overlooked role played by an efficient market trading system in maintaining and promoting the social division of labor, this paper focuses on uncertainties in transactions. An interesting point that maybe worthwhile to mention is that as the uncertainty in each single transaction activity on average is decreased, for instance due to an improvement in the market-oriented legal system, the specialization and social division of labor will be enhanced. As a result the expected utility of the agent is also improved; but the risk for the whole trading network to break down may nonetheless increase, since the increase in the number of transaction activities and trading volumes may outweigh the reduction of uncertainty in each transaction. Globalization brings together formerly isolated markets and thereby exploits the economies of the enhanced international division of labor on the one hand, and may increase the risk of coordination failure on the other. The often heard voices against globalization may appear to be rooted in some economically justifiable anxiety about the increasing uncertainty.

Appendix 1

We show the negative effect of risk aversion on the division of labor. By Eq. (4), $\partial n^*/\partial\rho<0$ if and only if $\partial\{\rho\ln[E(k^{1/\rho})]\}/\partial\rho<0$. Noting $\partial E(k^{1/\rho})/\partial\rho$ $=\int-\rho^{-2}k^{1/\rho}(\ln k)f(k)\ =-E[k^{1/\rho}\ln(k^{1/\rho})]/\rho$ where $f(k)$ is the probability density function of k, we obtain $\partial\{\rho\ln[E(k^{1/\rho})]\}/\partial\rho=\ \ln[E(k^{1/\rho})]-\ E[k^{1/\rho}\ln(k^{1/\rho})]/E(k^{1/\rho})$. But $E(k^{1/\rho})\ln[E(k^{1/\rho})]\ <E[k^{1/\rho}\ln(k^{1/\rho})]$ follows from Jensen's inequality due to the fact that $x\ln(x)$ is convex for any $x>0$. Thus, $\partial\{\rho\ln[E(k^{1/\rho})]\}/\partial\rho<0$.

Appendix 2

We analyze in this appendix the inter-occupational wage gap and specialization gap and in the asymmetric model. The interior solution of the maximal expected utility of occupation h requires $p^{1/\rho}E(k^{1/\rho})<1$. Equalization of expected utilities across occupations (refer to Eq. (8) and (9)), after some algebraic manipulation, leads to,

$$R(p,C_h,C,E(k^{1/\rho}),m,\rho)$$

$$\equiv(m+\frac{C_h}{C}-\frac{L}{C})\ln(p^{1/\rho})+\frac{m}{\rho}\cdot\ln\{\frac{\ln[E(k^{1/\rho})]}{\ln[p^{1/\rho}E(k^{1/\rho})]}\}+(\frac{C_h}{C}-1)\ln[E(k^{1/\rho})]=0 \qquad \text{(A.1)}$$

from which follows $p>1$ (as the left hand side of the above would otherwise be negative). Thus, the difference in the range of traded commodities between the human capital intensive occupation and others, by Eq. (8) and (9), equals

$n_h^* - n_{-h}^* = \frac{C_h}{C} - 1 + \frac{m}{\rho} \cdot \frac{\ln(p^{1/\rho})}{\ln[E(k^{1/\rho})]\ln[p^{1/\rho}E(k^{1/\rho})]}$ >0. It can be further shown from (A.1) that, $\partial p/\partial C_h > 0$, $\partial p/\partial C < 0$ and $\partial p/\partial \ln(Ek^{1/\rho}) < 0$. Since the increased knowledge may increase the training time in both occupation h and other ones, the effect knowledge on the wage ratio would depends on which effect dominates. Formally, $\partial p/\partial H = (\partial p/\partial C)(\partial C/\partial H) + (\partial p/\partial C_h)(\partial C_h/\partial H)$

$= \frac{\rho p}{n_h^*}\{\frac{C' L \ln p}{\rho C^2} + \frac{C_h}{C}(\frac{C_h'}{C_h} - \frac{C'}{C})\ln[p^{1/\rho}E(k^{1/\rho})]\}$. It follows, noting $p > 1$, $\partial p/\partial H > 0$ when $C_h'/C_h \geq C'/C$, or $\eta_h \geq \eta_{-h}$, where $\eta_h(\eta_{-h})$ is the knowledge elasticity of fixed investment in occupation h $(-h)$. $C_h'/C_h \geq C'/C$. The specialization gap $l_h^* - l_{-h}^* =$

$\{1 - \frac{1}{\rho \ln[E(k^{1/\rho})]}\}(C_h - C) - \frac{C}{\rho \ln[E(k^{1/\rho})]} \cdot \frac{m \ln(p^{1/\rho})}{\rho \ln[E(k^{1/\rho})]\ln[p^{1/\rho}E(k^{1/\rho})]}$

$+ n_h^* \frac{C}{\rho} \cdot \frac{\ln(p^{1/\rho})}{\ln[E(k^{1/\rho})]\ln[p^{1/\rho}E(k^{1/\rho})]}$ is positive and increases with C_h (note n_h^* and $\frac{\ln(p^{1/\rho})}{\ln[E(k^{1/\rho})]\ln[p^{1/\rho}E(k^{1/\rho})]}$ increase with C_h).

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