Leapfrogging in Technological Leadership and Uneven Growth

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Parente and Prescott (1993) proposed four development facts after studying per-capita GDP data of 102 countries over 1960-85 period. In this paper, we model economic and technological leapfrogging and the phenomenon of uneven growth suggested by their study. In our model, leapfrogging occurs because of the nature of technological changes and uneven growth concerns the amount of national knowledge stock that exists when a new technology arrives. Our model is one of 2-good 3-country Ricardian model. There are two sectors, food and manufacturing. Three countries compete to have comparative advantage in manufacturing sector which is growth generating. (*JEL* Classification: F43)

I. Introduction

During the last decade, there have been much concerns and lots of debates on US's loss of competitiveness in international markets. US economy has shown a poor performance for the last 20 years. Since 1973, output per worker has risen at only a 0.8% annual rate, compared with a 2.5% rate over the previous 25 years. Trade balance of goods and services has remained negative since 1971 with the exception of 1973 and 1975.[1]

On the other hand, other industrial nations have been enjoying

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[1]Trade balance marked US$ 1.3 billion deficit in 1971 for the first time after World War II. The upward trend has continued until 1996 when the trade deficit recorded US$ 186.1 billion

rapidly improving living standards during this period. And these countries, especially Japan, have been laying out the groundwork for even better times ahead by investing heavily in future productivity growth. Japan has been spending 3% of gross domestic product on nondefense R&D, both public and private, compared with 1.9% for US from 1982 throughout 1991. Japan has poor natural endowments and has emerged from World War II with very limited capital resources. Japan, however, has gained competitive advantage over US and other advanced nations in shipbuilding, steel, consumer electronics, automobile, and semiconductors, one after another over the last 40 years.

While Japan has succeeded in industrialization and gained comparative advantage in capital intensive sector and knowledge intensive sector, countries like India, Egypt, and many African nations have remained as underdeveloped countries for a long time. Those countries seem to stagnate in low growth traps, exhibiting persistently low rates of growth or relatively low levels of economic development (Azariadis and Drazen 1990). We may mention many factors that might have caused these countries to remain underdeveloped: political systems, social norms, population size, lack of natural endowments, inefficient government, and so on.

The story of narrowing gap and possibility of switch in economic and technological leadership between US and Japan is only one of the episodes in economic history which can be observed. The economic and technological leadership of Holland in 18th century was overtaken by England, and that of England was dominated by US and Germany in recent history.

Parente and Prescott (1993) suggest four development facts after studying per-capita GDP data of 102 countries during the 1960-85 period.[2]

(1) In every year studied, there is great wealth disparity among countries. In 1985, for example, the highest-output countries were 29 times richer than the lower-output countries (great disparity between rich and poor).

(2) Wealth disparity has not increased or decreased. The distance between the richest and poorest countries remained the same

[2]Parente and Prescott claim that "Theories of economic development must be able to account for the four development facts. Any theory that fails to do so simply is not a development theory."

throughout the 1960-85 period (constancy of that disparity over time and within the range of the distribution).

(3) The wealth distribution has shifted up: the richer got richer, but the poor did too. Therefore, no absolute poverty trap exists (upward shift of the distribution).

(4) There have been development miracles and disasters. During the 1960-85 period, 10 countries increased their wealth relative to the wealth leader by a factor of 2 or more. These miracles were matched by an equal number of development disasters: during the same period, the relative wealth of another 10 countries decreased by a factor of about 2 (demonstrated ability of some countries to spectacularly change their positions within the wealth distribution).[3]

Fact one and two remind us the story of uneven growth, and fact three and four are related with economic and technological leapfrogging. In this paper, we model such economic and technological leapfrogging and the phenomenon of uneven growth. In our model, leapfrogging occurs because of the nature of technological changes and uneven growth concerns the amount of national knowledge stock when a new technology arrives.

There are two kinds of technological changes. Most of the time, technology improves gradually by learning by doing, and it occurs in those countries with established advantages in technologically progressive sectors. At interval, there arrive new advanced technologies which require a country to start fresh to adopt the technologies (Brezis, Krugman, and Tsiddon 1993).

Our model is one of 2-good 3-country Ricardian model. There are two sectors, food and manufacturing. Three countries compete to have comparative advantage in manufacturing sector which is growth generating. In our model, knowledge stock is essential to the production of manufactured good and is accumulated by learning by doing (Young 1991). Under the comparative advantage reversal (CAR) setting, the country with larger knowledge stock participates in the CAR race and is able to compete for the comparative advantage in manufacturing sector, while the country with poor knowledge stock cannot participate in the race and

[3]Nations of 10 development miracles during 1960-85 are Saudi Arabia, Lesotho (in Southeastern Africa), Taiwan, Hong Kong, South Korea, Egypt, Congo, Japan, Singapore, and Syria. Nations of 10 development disasters are Zambia, Mozambique, Madagascar, Angola, Chad, Liberia, Ghana, Zaire, Nicaragua, and Afghanistan.

remains underdeveloped.

The paper consists of six parts. The first section introduces the issues and the second lays out the basic structure and assumptions of model. In section three, we describe the full specialization equilibrium. Section four describes the partial specialization equilibrium and discusses the transition. In section five, we explain the process of CAR and how the country without knowledge stock is trapped at underdevelopment. Section six concludes the paper.

II. The Model

Our model is a modification of 2-country 2-good model of Brezis, Krugman, and Tsiddon (1993). Our environment is as following. There are two kinds of goods, food and manufactured good. Food is technologically stagnant good and manufactured goods are a set of technologically progressive and growth generating goods. There are three countries and we designate them as U, J, and I. Initially, country U is a developed country completely specializing in manufactured good. J and I are less developed countries completely specializing in food. J and I have knowledge stock from the past which enhances the productivity of the manufactured good, but the knowledge stock of J is larger than that of I. The labor is the only factor of production. Three countries have equal labor forces, L.

We assume constant returns to scale in food production. The productivity of labor in food in three countries are the same and the productivity of labor in food production is equal to 1. Therefore, output of food in each country is equal to the amount of labor employed in food sector; that is,

$$
\begin{aligned}
F^U &= L_F^U \\
F^J &= L_F^J \qquad (1) \\
F^I &= L_F^I
\end{aligned}
$$

where F^U, F^J, and F^I are the amount of food produced in each country and L_F^U, L_F^J, and L_F^I are the amount of labor employed in food sector in three countries.

Manufactured goods consist of a series of increasingly sophisticated generations of goods. We assume that they are the perfect substitutes. Within each generation of goods, production is subject to learning by doing and we assume that there is no knowledge spillover across countries.

Assuming that $M_i^J(t)$ is the country J's rate of output of manufactured good of generation i at time t, the current output at T is

$$M_i^J(T) = A_i^J(K_i^J(T))L_i^J \tag{2}$$

$$\text{where } K_i^J(T) = \int_{-\infty}^{T} M_i^J(t)dt + K_0^J$$

$$j = U,\ J,\ I.$$

A_i represents the productivity of i-th technological generation and K_i^j is the knowledge stock accumulated through learning by doing while producing manufactured goods of technological generation i, plus K_0^J, which is the knowledge stock of country j before the introduction of i-th technological generation. K_0^J, which is exogenous in our model, comes from the experience of country j in producing manufactured goods using all the past technologies or can be accumulated by investing in education and R&D.

We assume $A' > 0$ and $A'' < 0$; that is, there are positive learning by doing effects, but learning is subject to diminishing returns as each technological generation matures.

For demand, we assume Cobb-Douglas utility function identically in three countries,

$$U = C_M^{\alpha} C_F^{1-\alpha}, \tag{3}$$

where C_M is the consumption of the manufactured goods, C_F the consumption of food. We also assume that the share α is greater than 1/3 and smaller than 2/3 to limit the number of equilibrium possible in our model.

While three countries have the same productivity in food production, they have different productivity in manufactured good production except when one of the countries is passing the other in productivity. We assume $A_i^U > A_i^J > A_i^I$ initially. These differences arise from the differences in the amount of knowledge stock accumulated in each country.

Our model is 2-good 3-country model and we have five kinds of equilibrium in general. First, all three countries produce manufactured goods and only one of them produces both goods. The workers in three countries receive the equal wage in this equilibrium.

Second, two countries specialize in manufactured goods and one specializes in food. In this case, the wages are determined by demand. Third, one specializes in manufactured goods, one in food, and the other produces the both food and manufactured goods. The workers in three countries receive the equal wage. Fourth, two countries specialize in food and one country in manufactured goods. The wages are demand-determined. Fifth, all the three countries produce food and only one of them produces both. The workers in three countries receive the equal wage in this case, too.

By assuming that $1/3 < \alpha < 2/3$ and that three countries have the same labor forces L, we rule out first, second and fifth kinds of equilibrium (See Appendix for proof). In the following two sections, we will consider a transition from the full specialization to the partial specialization, then to the full specialization equilibrium.

III. The Full Specialization Equilibrium

In this section, we describe the full specialization equilibrium in which two countries produce only food and the third produces only manufactured goods. In this case,

$$L_M^U = L_F^J = L_F^I = L.$$

Given the world expenditure E, the share α goes to manufactured good and the share $1-\alpha$ to food. Therefore,

$$\begin{aligned} W^U L &= \alpha E \\ W^J L + W^I L &= (1-\alpha)E. \end{aligned} \tag{4}$$

Since the wages are equal for two countries which produce food, $w^J = w^I = w$, we have

$$2wL = (1-\alpha)E. \tag{5}$$

Thus

$$\frac{W^U}{W} = \frac{2\alpha}{1-\alpha}. \tag{6}$$

The full specialization equilibrium will sustain as an equilibrium only if this relative wage rate does not exceed A_i^U / A_i^J and A_i^U / A_i^I; that is,

$$W \frac{1}{A_t^J} > W^U \frac{1}{A_t^U}$$
$$W \frac{1}{A_t^I} > W^U \frac{1}{A_t^U} \; . \tag{7}$$

In the full specialization equilibrium, the price of manufactured goods in terms of food is

$$\frac{P_M}{P_F} = \frac{2\alpha}{(1-\alpha)A_t^U} \; , \tag{8}$$

and the real wage rates are

$$\omega^U = \gamma \, (A_t^U)^\alpha \left(\frac{2\alpha}{(1-\alpha)A_t^U} \right)^{1-\alpha}$$
$$\omega^J = \gamma \left(\frac{(1-\alpha)A_t^U}{2\alpha} \right)^\alpha \tag{9}$$
$$\omega^I = \gamma \left(\frac{(1-\alpha)A_t^U}{2\alpha} \right)^\alpha ,$$

where $\gamma = \mu^{\mu}(1-\mu)^{1-\mu}$ and μ is the coefficient to the price index.

During this period, relative wages among three countries are fixed. As the productivity of U grows, the relative price of manufactured good declines and real wage rates for three countries increase. Notice that the real wage rates for all the countries depend only on the productivity of country U, and the real wage rate of U which completely specializes in manufactured goods is bigger than those of J and I which completely specialize in food. Country J, which is underdeveloped but has knowledge stock, and country I, which is also underdeveloped and have lesser knowledge stock, have the same real wage rate. Knowledge stock which is not employed in the production of manufactured goods doesn't contribute to the welfare of the nation.

At the initial equilibrium of full specialization, U's productivity will increase over time through learning by doing as it produces more of manufactured goods while those of J and I remain constant. Since productivity gap between U and J (and I) gets bigger over time given the technological generation, there exists no way to switch the pattern of specialization.

IV. The Transition: The Partial Specialization Equilibrium

In this section, we consider the partial specialization equilibrium where country U produces only manufactured goods, and country J produces both manufactured goods and food, and country I produces only food. In such an equilibrium,

$$\frac{W^U}{W^J}=\frac{A_t^U}{A_t^J}=\frac{W^U}{W^I}$$
$$\frac{W^U}{W^I}<\frac{A_t^U}{A_t^I} \tag{10}$$
$$\frac{W^J}{W^I}<\frac{A_t^J}{A_t^I}.$$

We can determine the allocation of country J's labor between food and manufactured goods. Assuming food to be the numeraire, the world income is

$$Y=\left(\frac{W^U}{W^J}+2\right)L. \tag{11}$$

Now, world spending on food should be equal to world income from food production:

$$P_F(1-\alpha)L\left(\frac{A_t^U}{A_t^J}+2\right)=P_F(L_F^J+L). \tag{12}$$

Thus

$$L_F^J=\{(1-\alpha)\frac{A_t^U}{A_t^J}+1-2\alpha\}L. \tag{13}$$

The price of manufactured goods in terms of food is

$$\frac{P_M}{P_F}=\frac{1}{A_t^J}, \tag{14}$$

and real wage rates of three countries are

$$\omega^U=\gamma A_t^U(A_t^J)^{-(1-\alpha)}$$
$$\omega^J=\gamma(A_t^J)^{\alpha} \tag{15}$$
$$\omega^I=\gamma(A_t^J)^{\alpha}$$

$$\text{where } \gamma = \mu^{\mu} (1-\mu)^{U}.$$

In the partial specialization equilibrium, relative wages change as productivity of country U and J change. Price of manufactured good in terms of food now depends only on the productivity of country J. And as J's productivity rises, price of manufactured good falls.

Notice that ω^U depends on the productivities of country U and J, and both ω^J and ω^I depend only on the productivity of country J. Since only U and J are producing the manufactured goods in the partial specialization equilibrium, only their productivity coefficients appear in real wage rates. Also note that Country I maintains the same level of real wage as J does. The reason is that the workers in two countries receive the same level of wage even after J begins to produce manufactured goods.

For both partial and full specialization equilibrium, real wage rates for country J and C are equal. This implies that countries specializing at food can obtain relatively better real wage than others only by gaining comparative advantage in manufacturing and specializing in it. Even though country J has more knowledge stock than country I, knowledge stock is useful to improve the living standards only when it is used to produce manufactured goods and the country acquires the comparative advantage in manufactured goods.

V. Comparative Advantage Reversal and Underdevelopment Trap

We assume that world economy is in full specialization equilibrium initially where country U has the comparative advantage in manufacturing sector. Suppose that a new technology of generation $i+1$ is introduced. The new technology is better that the old in that it yields the higher productivity given the same amount of experience. The new technology, however, is initially inferior to the old for U which has extended experience on the old technology. Therefore, individual producers in U has no incentive to replace the old technology by the new. In contrast, J and I have low wages and do not have experience on the old technology. We assume that new technology is profitable to only J so that

$$
\begin{aligned}
&W \frac{1}{A^{J}_{t+1}\,(K^{J})} < W^{U} \frac{1}{A^{U}_{t}\,(K^{U})} \\
&W \frac{1}{A^{I}_{t+1}\,(K^{I})} > W^{U} \frac{1}{A^{U}_{t}\,(K^{U})}\,.
\end{aligned}
\tag{16}
$$

Since $w^J = w^I$ and $K^J > K^I$, $A_{t+1}(K^J) > A^I_{t+1}(K^I)$. Thus only J is able to introduce new technology and starts to produce manufactured goods.

As J begins to produce manufactured goods, pattern of specialization shifts from full to partial specialization. We also assume that J's productivity of $i+1$-th generation of technology rises more rapidly than U's i-th generation of technology does so that it catches up and surpasses the U's productivity eventually. As J's productivity rises, J's employment in food sector falls and in manufactured sector rises. Real wages in J and I will steadily rise. U's relative productivity, however, will get worse since J's productivity grows faster than U's. This could lead to a declıne in U's real wage rate.

Country I will benefit from the shift of the specialization pattern since the value of its food production will rise. That is, during the partial specialization period, total world production of food declines compared with the full specialization equilibrium. Therefore, the value of food production of country I rises even though I produces the same amount of food.

At the point where productivity of J surpasses that of U, the reversal of the specialization pattern occurs. Country U which has completely specialized at manufactured goods and exported manufactured goods while importing food, now produces both food and manufactured goods. Country J which produces both manufactured goods and food previously completely specializes at manufactured goods, and begins to export manufactured goods and import food at the reversal.

As the productivity of J surpasses that of U enough so that $A^J_{t+1}/A^U_t > 2\alpha/(1-\alpha)$, we reach the full specialization again and a cycle of CAR is completed. At this point, U specializes at food and J at manufactured goods.

After the completion of the reversal, country U is now at the position to seek another round of CAR when the next generation of technology is introduced. Country I which could not participate in the CAR race in the past due to poor knowledge stock is still at the inferior position to country *U*. While country *U* has knowledge stock from the previous experience in producing manufactured goods, country *I* doesn't. Therefore, at the introduction of the next generation of technology, country *U* will have an advantage in accepting the new technology over country *I*. This means that country *I* which has poor knowledge stock remains underdeveloped while other countries compete for economic growth. The lack of knowledge stock traps country *I* to remain as underdeveloped while country *J*, which has knowledge stock, could participate in CAR and gain comparative advantage in manufactured goods and enhance the national welfare relatively to others.

Now, we examine the change in welfare of three countries during the process of CAR. As the world economy shifts from full to partial, and then to full specialization equilibrium, real wage of each country also changes. Real wage of *U* keeps declining throughout the process. Thus, country *U* loses as a result of CAR. Since manufactured sector is growth generating, to lose comparative advantage in manufactured good is directly translated into the welfare loss. On the other hand, country *J* gains by the reversal. Since *J*'s productivity in manufactured goods grows over time, its real wage keeps rising during and after CAR.

The path of real wage that country *I* takes is different from those of *U* and *J*. Real wage of *I* rises when the world economy shifts from full to partial specialization equilibrium. World production of food declines as the result of the shift and the value of food production of *I* rises. However, as the world economy shifts from partial to full specialization, world food production increases since *U* and *I* produce food now, and therefore, real wage rate may be depressed since A_{t+1} increases.

Note that the above discussion on the changes in welfare is on the relative basis. Because the productivity increases over time through learning by doing and by the introduction of the new technology, absolute level of welfare of each country will trend upwards. In particular, absolute level of welfare in country *I* will rise over time while it's relative level stays low. The involvement in the world trade benefits country *I* even though it's not producing manufactured goods itself.

VI. Conclusion

We have examined the process in which reversal of comparative advantage occurs as the new technology is introduced and the country with poor knowledge stock falls in underdevelopment trap and can not take part in CAR to attain economic growth.

In our model, whether a country has relatively higher knowledge stock which can be utilized to gain advantage in accepting the new technology has been the focal factor that determines whether the country can get comparative advantage in growth generating sector.

Our findings are the following. First, leapfrogging (or reversal of comparative advantage) is possible because of the initial inferiority of the new technology to old for U and the lower wage of the following country. Second, a country with no knowledge stock or with relatively poor knowledge stock could fall in the under-development trap and may not participate in the CAR race. Third, welfare of the country with poor knowledge stock still rises because trade of manufactured goods allows the country to enjoy the benefit of productivity growth of other countries. Fourth, the knowledge stock may play a crucial role in the process of CAR and economic growth.

Appendix

Suppose that all the countries produce food and one of them produces both goods. Now, total world expenditure on manufactured goods is $3\alpha wL$ and income from selling manufactured good is wL_M. This implies $3\alpha L = L_M$. Given $\alpha > 1/3$ and the labor forces across countries are equal, however, this implies $L_M > L$. Therefore, this equilibrium is impossible. Next, consider the equilibrium where all the countries produce manufactured goods and one of them produces both goods. Total world expenditure on manufactured goods is $3\alpha wL$ and total world income from manufactured goods is $2wL + wL_M$. This implies $(3\alpha - 2)L = L_M$. Given $\alpha < 2/3$ and the labor forces across countries are equal, however, this implies $L_M > L$. Therefore, this equilibrium is also impossible. Finally, consider the equilibrium where two countries produce only manufactured goods and third country produces only food. Suppose the world is at this equilibrium initially. Now, if new technology arrives and third country begins to produce the manufactured goods, the new equilibrium is the first kind which is impossible in our model given restrictions. Therefore, this equilibrium is also excluded.

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References

Azariadis, Costas, and Drazen, Allan. "Threshold Externalities in Economic Development." *Quarterly Journal of Economics* 105 (1990): 501-26.

Becker, Gary S., Murphy, Kevin M., and Tamura, Robert. "Human Capital, Fertility, and Economic Growth." *Journal of Political Economy* 98 (October 1990): Part 2, 12-37.

Brezis, Elise S., Krugman, Paul R., and Tsiddon, Daniel. "Leap-frogging in International Competition: A Theory of Cycles in National Technological Leadership." *American Economic Review* 83 (December 1993).

Clarida, R. H., and Findlay, R. "Endogenous Comparative Advantage, Government, and the Pattern of Trade." NBER Working Paper 3813, May 1991.

Grossman, Gene. "Explaining Japan's Innovation and Trade: A Model of Quality Competition and Dynamic Comparative Advantage." NBER Working Paper 3194, December 1989.

__________, and Helpman, E. *Innovation and growth in the Global Economy*. Cambridge, MA.: MIT Press, 1991.

Fudenberg, Drew, Gilbert, Richard J., Stiglitz Joseph, and Tirole, Jean. "Preemption, Leapfrogging, and Competition in Patent Races." *European Economic Review* 22 (1983): 3-31.

Lucas, Robert. "On the Mechanics of Economic Development." *Journal of Monetary Economics* 22 (1988): 3-42.

Maddison, Angus M. *Phases of Capitalistic Development.* Oxford: Oxford University Press, 1982.

Olson, Mancur. *The Rise and Decline of Nations.* New York: Free Press, 1982.

Parente, Stephen L., and Edward, Prescott C. "Changes in the Wealth of the Nations." *Quarterly Review*, Federal Reserve Bank of Minneapolis (Spring 1993).

Porter, Michael E. *The Comparative Advantage of Nations.* New

York: The Free Press, 1990.

Romer, Paul. "Endogenous Technological Change." *Journal of Political Economy* 98 (October 1990): 71-102.

Tirole, Jean. *The Theory of Industrial Organization.* Cambridge, MA: MIT Press, 1988.

Young, Alwyn. "Learning by Doing and the Dynamic Effects of International Trade." *Quarterly Journal of Economics* 106 (May 1991): 396-406.