INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book. These are also available as one exposure on a standard 35mm slide or as a 17" x 23" black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI
University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700  800/521-0600
Three essays on technological progress and international trade

Chen, Shiao-Ping, Ph.D.

Rice University, 1989
RICE UNIVERSITY

THREE ESSAYS ON TECHNOLOGICAL PROGRESS
AND INTERNATIONAL TRADE

by

SHIAO-PING CHEN

A THESIS SUBMITTED
IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE
DOCTOR OF PHILOSOPHY

APPROVED, THESIS COMMITTEE

Peter Mieszkowski, Professor, Chair
Department of Economics

Gordon W. Smith, Professor
Department of Economics

T. Clifton Morgan, Assistant Professor
Department of Political Science

Houston, Texas
April, 1989
ABSTRACT

THREE ESSAYS ON TECHNOLOGICAL PROGRESS
AND INTERNATIONAL TRADE

SHIAO-PING CHEN

The thesis is divided into three essays. In the first essay, a two-by-two model is formulated in which changes in price are caused by technological progress that takes place in one sector. It is found that the factor used intensively in the sector where technology advances will be better off in terms of both goods if the proportionate decrease in the price of that good is less than the proportionate increase in productivity; the other factor, although it suffers from the change in factor intensity, may still be better off due to the improvement in productivity.

The second essay deals with technology that is accessible to everyone in the economy. Since technology is a public good, it pays to devote more resources in the creation of new technology if the population size is larger; productivity increases as the investments for new technology increase. The optimal level of population is reached when the positive effect of increased productivity is balanced by the negative effect of the increased labor size.

The third essay discusses two topics: first, the optimal level of technology acquisition; second, the international indebtedness. Productivity will increase because of the acquired technology; however, the secondary burden of the royalty payments will turn the terms of trade against the adopting country. The optimal level of technology acquisition is then reached when the gains from the
acquired technology are balanced by the losses from the worsening terms of trade. In the second part of the third essay, the advanced country temporarily falls behind in the creation of technology but expects to regain the leading margin in productivity. Both countries can be better off if the advanced country now borrows from the backward country and pays the loan back with interest when the leading margin in technology of the advanced country is reestablished in the future.
ACKNOWLEDGEMENTS

Glory to God! Without Him, this thesis would have never been wrapped up. God pulled me through the hardest time I have ever experienced in my life and has summoned me to serve His church in Boston.

The basic idea of this thesis sparkled when I was taking an international trade course from Dr. Smith some years ago; Dr. Mieszkowski helped me develop the Hicksian model; Mr. Owen McCrory, my supervisor and friend at the M. D. Anderson Cancer Center, has been the major booster of mine throughout the years I worked for him. Many a friends also have helped me weather the hardship: Long-jin, whose support always came in the nick of time; tennis pals, Tony Ip, Steve and Tony Tung, who have strengthened my physical and spiritual vitality; Ming-ching and wife, who were my helpful consultants; their son, Kelvin, from whom I have taken a lot of time with which he would have enjoyed much of his parents' company; Ching-fong, who provided me with meals when I was too depressed to cook; I-feng, who advised me in Buddha before I converted myself into a Christian; Bianca, who led me into the kingdom of God on February 8, 1989; and, of course, Shiow-yun, whose nightly phone calls from New York have been part of my daily diet for the past year.
# TABLE OF CONTENTS

Chapter 1 : Introduction .................................................. 1

Chapter 2 : Distributional Effects of Technological Progress .......... 5
  Literature Review ......................................................... 8
  The Stolper-Samuelson Theorem with
    Technological Progress ........................................... 21
  The Complete Model .................................................. 28
  Factor Movements ...................................................... 40
  Concluding Remarks .................................................. 43
  References to Chapter 2 ................................................. 45
  Appendix to Chapter 2 ................................................ 50

Chapter 3 : Technology as a Public Good and its Implications in
  Labor Migration .......................................................... 58
  Literature Review ...................................................... 60
  Technology as a Public Good ......................................... 67
  The Equilibrium Relative Wage Rate and Specialization ............. 76
  The Optimal Population Migration .................................... 81
  Concluding Remarks ................................................... 88
  References to Chapter 3 ................................................ 90

Chapter 4 : The Optimal Technology Acquisition and
  Technology-Induced International Indebtedness ....................... 94
  The "Secondary Burden" of Transfer Payments ........................ 95
  The Optimal Level of Technology Acquisition in a
    Ricardian Model with Non-tradables ................................ 98
  Technology-Induced International Indebtedness
    in the Absence of Non-tradables .................................. 106
  Concluding Remarks ................................................... 111
  References to Chapter 4 ............................................... 113
CHAPTER ONE

INTRODUCTION

Back in the early 1950's, McDougall had already found that the U. S., despite of its higher wage rate, was replacing the role of the U. K. in exporting manufacturing goods to the world market because the U. S. leading margin in labor productivity was larger than the difference in wage rates. ¹ Hicks also argued that the shortage of dollars in Britain was a consequence of increasing labor productivity in the U. S. manufacturing sector.² Since Hicks, a number of economists have elaborated on the role of technology in international trade theory.³

This dissertation is an attempt to explore three aspects of technological progress in the context of international trade: the welfare effects of technological change on the nation as a whole and on the specific production factors, the regulation of technology dissemination and the impact of technological progress on labor migration.

The welfare effects of technological progress on a nation as a whole have received much attention in the literature; the effects on individual factors have not been fully treated. In order to investigate the welfare implications on factors, the conventional Stolper-Samuelson Theorem is generalized to incorporate technological changes so the Stolper-Samuelson type of results can be derived. This, in essence, is a formal treatment of Hicks' analysis in a two-sector model. It is found that the relative magnitude of the change in the price and in technology is crucial for the welfare effects in question: the factor used intensively in the advancing sector gains only when the proportionate change in the price of that good is less than the technological progress. The underlying forces that determine the magnitude of price change are the price elasticities of demand in both countries: the higher the elasticities are, the less the price falls.

Technology as a public good is the second issue discussed in this dissertation. As noted by some authors, the central planner of an

---

4 Effects on individual factors are treated in many works; however, expressing factor returns in their ratio makes the derivation of the Stolper-Samuelson type of results impossible and the welfare effects of factors in terms of goods can not be determined.

5 For the original version of the Stolper-Samuelson Theorem, ...
economy will devote a certain proportion of the labor force to innovative activities. As the technology is a public good, the "optimal" size of labor force becomes an issue and some criteria regarding the regulation of immigration can be derived. For a larger labor force, more labor is devoted to the creation of technology and general productivity increases; this positive effect has to be balanced against the negative effect of the deterioration of the terms of trade resulting from the increase in population. The optimal size of labor force is reached when these two effects are in balance.

Technology dissemination is attracting more attention as competitiveness becomes a crucial issue in international trade. Countries that have difficulties in developing innovations can import technology to raise productivity. The acquired technology will increase productivity but, in the presence of nontradable goods, the terms of trade will go against the country importing the new technology. Hence the problem faced by the adopting country is to purchase new technology up to a point where the negative

---

5 ... see W. Stolper and P. A. Samuelson, "Protection and Real Wages", Review of Economic Studies, 9(1941): 58-73. Efforts have been devoted to the generalization of this theorem to include many-good-many-factor cases; however, the changes in price remain exogenous. In this work, changes in price are resulted from technological change. For a Stolper-Samuelson Theorem with many goods and many factors, see, for instance, W. W. Chang, "Some Theorems of Trade and General Equilibrium with Many Goods and Factors," Econometrica, 47(1979): 709-726.

6 This has been derived by T. A. Pugel in a two-sector model, see T. A. Pugel, "Endogenous Technological Change and International Technology Transfer in a Ricardian Trade Model," Journal of International Economics, 13(1982):321-335.

7 This is not a Pareto optimality because compensational payments are not considered.
terms-of-trade effect is equal to the positive productivity effect.

As technology changes, the balance of trade is disturbed. The last part of this dissertation outlines a model in which the international indebtedness is motivated by the expectation of technological advancement in the future; to maximize intertemporal utility, a country expecting technological improvements in the future has the incentive to borrow and a country expecting static technology in the future tends to make the loan. This model studies the trade imbalance for a technology-mature country whose technological lead temporarily diminishes.

The welfare effects of technological progress on production factors is the issue in the next chapter; Chapter Three treats the newly created technology as a public good and then derives the optimal level of labor migration; the optimal level of technology acquisition and technology-induced international indebtedness constitute the subject matter of Chapter Four.
CHAPTER TWO

DISTRIBUTIONAL EFFECTS OF TECHNOLOGICAL PROGRESS

Hicks' *Inaugural Lecture* \(^1\) is a seminal paper for exploring the significance of technological progress in modern trade theory. He characterizes the nature of technological progress---which may be sector-neutral, import-biased or export-biased, and illustrates the implications of technological progress on the economy. Many economists have elaborated Hicks' model to study how technological progress affects the economy.\(^2\) This literature is primarily concerned with the *direction* of change in the terms of trade resulting from technological progress, and in deriving the changes in the trade pattern, resource allocation and income distribution between two countries. There is a consensus on the conditions that determine the

---


change in the terms of trade. But the distributional effects of technological progress have not been fully treated yet. The issue studied in this chapter is: Even if the conventional wisdom set down by Hicks holds, namely, the export-biased technological progress generally benefits the rest of the world while the import-biased technological progress may hurt the rest of the world, it is possible that the welfare effects for a particular factor may well go against the welfare effects for the country as a whole; if the distributional effects are large, the equity aspect must be considered in justifying the desirability of technological progress that is biased to a sector.

To study the welfare effects on a particular factor, one needs to determine both the direction of the change in the terms of trade and the change in their magnitude. The basic relationship between product prices and factor prices in trade theory is the Stolper-Samuelson Theorem. However, the original form of the Stolper-Samuelson Theorem is not readily applicable when the production possibility frontier shifts as the result of factor increases or technological progress. The conventional form of the Stolper-Samuelson Theorem needs to be modified to incorporate technological progress.

The basic issues are as follows: Under what conditions will the price of a good fall as a consequence of technological progress that takes place in that sector? If the price does fall, how much would it

---

3 Hicks, "Inaugural Lecture."

fall? Since the product price is a weighted average of factor prices, how is the fall in the product price distributed to individual factor returns? Will the welfare of a factor increase or decrease in terms of a particular good?

This chapter outlines the conditions bearing on above questions. The effects of resource movements, production patterns, trade patterns and national income can also be analyzed.

In this chapter, technology serves as the source of the price change, and then the Stolper-Samuelson type of welfare results are derived. In the standard literature on the Stolper-Samuelson Theorem, the price change is taken as exogenous resulting from external disturbances such as tariffs. In this chapter, price changes have to be determined along with all other variables in the economy. In the literature surrounding Hicks' *Inaugural Lecture*, the distributional effects of technological progress on factors are not on center stage. Typically, the welfare effects on factors are treated in terms of wage-rental ratio which may be important for inquiring the relative income between factors. But on this approach it is not straightforward to show how a factor gains or loses with respect to a particular good. In this chapter, factor returns are related to each product price, and it is possible to determine the welfare effects on a particular factor in terms of individual goods.

This chapter focuses on the *magnitude* as well as *direction* of change while the primary emphasis of the existing literature is on the *direction* of change. It is useful to look at the direction of change if one is concerned with the welfare of the country as a whole; however,
what really matters, from the standpoint of the individual factors, is
the magnitude of change in the price. As shown below, the welfare
implications for a particular factor could change signs if the price
change reaches a certain level. Thus, I analyze by how much the
price change needs to be in order to improve or decrease the real
income of a particular factor. In contrast, the existing literature
derives the conditions under which the price will go up or down once
the technological progress takes place to an industry.

The rest of this chapter first surveys the literature surrounding
Hicks' Inaugural Lecture and the Stolper-Samuelson Theorem; then
the conventional Stolper-Samuelson Theorem is modified to
accommodate technological progress. A complete model is then built
to determine the price change.

Literature Review

The relevant literature can be classified into two strands. One is
the works regarding technological progress in the context of
international trade; the second is the works analyzing the relationship
between product prices and factor prices. As Johnson puts it, Hicks' Inaugural Lecture is the modern origin for the study of technological progress in international trade theory\(^5\); this section begins with the Lecture.\(^6\) I then review the literature on the Stolper-Samuelson

---


\(^6\) For the pre-Hicksian development, see, e.g., Hojera, Welfare Implications.
Theorem.

In an attempt to respond to what he calls "the fundamental economic problem confronting this country", Hicks in his lecture at Oxford explained the "dollar shortage" in England with the rapid increase in the United States' productivity.\(^7\) In order to highlight the significance of technological progress, he starts out with a Ricardian model in which there is only one factor---labor, and the marginal cost of production is constant. He also assumes that trade is always in balance and therefore all the effects of technological progress will be reflected in the terms of trade. Before presenting the formal analysis, Hicks distinguishes the real(barter) effects from the monetary effects of productivity change, the former being those that persist through any necessary adjustments in money income; the latter, those caused by the adjustments of money income. His first proposition is, "If productivity in A is increasing uniformly---at the same rate in all of A's industries---the barter effects of the development are most unlikely to be harmful to B."\(^8\) He assumes that the price of A's exports remain unchanged immediately following the technical change and the money income of Country A will increase to the full extent of technological progress while the income of B will be unchanged. Under this assumption,\(^9\) A's demand for B's export would rise; if the

---

\(^7\) For comparison of productivity in the U. S. and England at about that time, see, e.g., G. D. A. MacDougall, "British and American Exports."

\(^8\) Hicks, "Lecture."

\(^9\) The approach that assumes the terms of trade remain the same monetarily and then shows the constant terms of trade can not be viable seems to be a typical practice in the papers along Hicks' line; see, e.g., R. Findlay and H. Grubert, "Factor intensities, Technological Progress and the Terms of Trade," Oxford Economic Papers, 7(1959) : 111-121.
trade is always in balance, the price of A's exports should fall. It follows that the increase in A's wage rate will be less than the increase in A's productivity, and part of the improvement in A's technology will accrue to B. This implies that, though the commodity terms of trade turn against the innovating country, the factorial terms of trade will move in its favor. Hicks also argues that as long as the progress is rapid, it is not likely that the improvement in A's factorial terms of trade will increase so much that the commodity terms of trade is reversed to hurt the rest of the world.

Hicks then moves on to the case where the technological progress is biased to either importables or exportables. He argues that if the productivity improves exclusively in A's export sector (export-biased), the price of A's exports would fall. Since the quantity of B's exports tends to increase or is at least constant, the value of B's exports will not be smaller. Consequently, the terms of trade turn to benefit B. Hicks deems that this case is to the best interests of B. However, if the productivity improves on the imports of A (import-biased), then B would be worse-off.\textsuperscript{10} In this case, the price and the quantity of A's imports (B's exports) fall. On the other hand, there is no reason for B's imports to fall (if income in both countries remains unchanged); consequently, the terms of trade will turn against B. The factorial terms of trade also turn against B in this case.

Hicks then applies his theory to an important issue facing England of his time. He argues that the Anglo-American economic relations

\textsuperscript{10} In a multiple-good model, this is not necessarily true; B simply gives up this sector and imports it from A at a lower price.
had been smooth throughout the nineteenth century because both countries were making progress in their export sectors; America made tremendous progress in its agricultural sector and England could rely on the cheap agricultural imports and specialized in producing manufacturing goods in which England had advantages. He then argues that the mutually beneficial type of development is just the first phase of economic development. He honors Adam Smith's idea that the division of labor is limited by the market and the productivity improvement resulted from the division of labor slow down eventually. If a country used to import a good but now possesses the resources and know-how for the production of that good, this country can introduce the previously imported good and the technological progress will be import-biased. He observes that since the end of last century, America has caught up rapidly in the manufacturing sector and England had been losing its competitiveness in the previously exporting goods. He concludes that the increasing productivity in the U. S. industry is the primary cause of England's dollar shortage.

Mishan¹¹ argues that if the production cost is increasing, then a certain level of positive income effect is necessary for the terms of trade to move to favor England in the case of export-biased as well as in the uniform type of technological progress that takes place in America. He uses the following figure to show the case of uniform technological progress:

Where PP and PP' represent the production possibility frontier before and after technological progress respectively. Suppose, initially, America wants to import quantity BQ of England's textiles. Since America increases its production in textiles as well as in grain, the income effect of America's demand for textiles falls short of SQ'. America will need less of England's textiles and the terms of trade would turn in favor of American and against England.

Mishan also argues that a positive value of America's income effect for textiles is also necessary for the terms of trade to move to favor England in the case where technology progress solely take place in America's grain sector. He says,\textsuperscript{12}

\textsuperscript{12} Mishan, "Dollar Problem."
Furthermore, even if the U.S. has a technological advance which is concentrated solely in grain production so that the new production possibility curve is to be drawn from P on the Y-axis to P' on the X-axis, provided only that a point B' on this new production possibility curve (whose tangent is parallel to that of B) is higher than B, some determinant positive income effect in favor of textile will be necessary if the terms of trade are to move in favor of the U.K.

Mishan's comment is generally true; however, as pointed out by Findlay and Grubert, factor-neutral technological progress limited to one sector has to be ultra-biased (namely, the production of the static sector actually decreases), given the pre-innovation terms of trade. In this case, B' will never be higher than B, and the positive income effect is not necessary for the terms of trade to move in favor of U.K. Mishan also makes it clear that the difference in the marginal propensities to consume must be taken into consideration. The terms of trade may turn against England if its marginal propensity to consume grain is much higher than the America's marginal propensity to consume textiles; in fact, the difference in the marginal propensity to consume can be so large as to reverse the movement of terms of trade. The significance of different marginal propensities to consume are also emphasized by Johnson.

An important extension concerning the welfare of innovating country was proposed by Bhagwati. He points out that the possibility

---

13 Findlay and Grubert, "Factor Intensities."
of welfare loss for the advancing country was not treated in Hicks' model.\textsuperscript{15} Allowing for the possibility of inelastic demand for the innovating good, Bhagwati adds a gloomy prospect for technological progress by formulating the conditions that might lead to what he calls "immiserizing growth".

Highlighting output and consumption elasticities, Johnson refines the arguments proposed by Hicks.\textsuperscript{16} He puts forward a case in which specialization is complete: Mancunia produces only manufacturing goods; Agraria produces only agricultural goods. Suppose the technological progress takes place in Mancunia, the terms of trade may turn against Mancunia if the improvement in Mancunia is so high that the Agraria's demand for imported manufacturing goods become inelastic. This suggests the possibility of "immiserizing growth". One implication of this analysis is that, under the assumption that the income elasticity of demand for manufacturing goods is greater than one and that for agricultural goods is less than one, the industrialization of a primary-producing country will make that country better off, because world economic progress is biased against primary production in the long run.

To deal with the case of incomplete specialization, Johnson defines "ultra-export biased", "neutral" and "ultra-import biased" type of

technological progress on the demand side as well as on the supply side and calculates the "net effect" to determine how the terms of trade would change.\textsuperscript{17} For instance, if technological progress takes place in the export sector only, the resultant consumption would be import-biased (because of the difference in the elasticity of demand for imports and exports), and the production is ultra-export-biased; the net effect could be import-biased or export-biased, depending on the relative strength of the two effects. Putting together all the case of technological progress, one can derive a set of results for changes in the terms of trade. Findlay and Grubert give an elegant diagrammatical exposition of technological progress.\textsuperscript{18} It takes three steps to complete their analysis. For the factor-neutral type of technological progress, if the capital-intensive good (textiles in their example) improves, the wage-rental ratio would tend to favor capital, and both sectors (textiles and wheat) will be more labor intensive relative to what they used to be. They then use an Edgeworth-Bowley box diagram to show the conditions under constant terms of trade that the production of wheat must shrink as a result of the technological progress in textiles; namely, the factor-neutral technological progress has to be ultra-biased. The third point in Findlay and Grubert is that, if the innovating country exports textiles and imports wheat,

\textsuperscript{17} On the production side, the expansion is "extra-export(import)" biased if the production of the import(export) actually decreases. On the consumption side, expansion is "neutral" if it increases the total demand for importables in the same proportion as it increases the demand for exportables; is "import-biased" if it increases the demand for importables in less proportion than it increases the demand for exportables; is "export-biased" for the opposite case of the "import-biased" case.

\textsuperscript{18} Findlay and Grubert, "Factor Intensities."
factor-neutral technological progress in wheat is ultra-import biased and the terms of trade shift in favor of the innovating country; the opposite applies if technological progress takes place in textiles.

With neo-classical production functions, Kemp shows how technological progress affects a small country with constant terms of trade. He finds that the factor intensively used in the sector where factor-neutral technological progress takes place will be better off while the other factor will be worse off. He also shows that the output expansion is ultra-biased, which is natural under constant terms of trade. Kemp's results are so clear-cut because the terms of trade are determined in the rest of the world. The welfare effects for factors are also unambiguous; namely, when one factor gains (loses), it gains (loses) in terms of both goods.

Following Kemps' scenario, Miller and Schwartz expand Kemp's conclusions and show that if the technological progress is much larger in the import industry than that in the export industry, the imported good will eventually be exported, regardless of factor endowments.

In an attempt to put together all the factors that influence comparative advantage, Amano sets up a model that integrates factor endowments, technological advantage, demand elasticities and production scale. Amano's paper is comprehensive in that it

includes all elements that may enter the determination of comparative costs; however, it leaves out all the effects on the terms of trade occurring in the rest of the world. This is a model that determines the pre-trade commodity price and examines, once the trade is open, how trade patterns may be changed by technological progress.

Amano's paper also deals with the change in relative factor price resulting from technological progress; however, it is not clear which factor will gain in terms of which good; factor prices expressed in relative terms do not provide this type of information.

The significance of Hojera's study is that it explicitly incorporates the influences at factors occurring in the rest of the world. In his model, the world is integrated so that everything depends on everything else. However, as his results are expressed in terms of the wage-rental ratio and the capital-labor ratio, it is not readily clear whether each factor gains or loses with respect to a particular good.

Stolper and Samuelson's study regarding the incidence of protective tariffs on the distribution of income turned out to be a cornerstone for the inquiry of the relation between product prices and factor prices. In their study, if the price of labor-intensive good increases as a consequence of tariffs imposed on it, labor will be better off not only in terms of the labor-intensive good and the

---

22 Hojera, *Welfare Implications*.
capital-intensive good, while capital loses in terms of both goods.

It is noteworthy that the effects of price changes on factor returns are sensitive to the difference in factor intensities. It can be shown that the change in the product price is just the weighted average of changes in factor prices:

\[ \theta_{L1} \hat{w} + \theta_{K1} \hat{r} = \hat{p}_1 \]  
\[ \theta_{L2} \hat{w} + \theta_{K2} \hat{r} = \hat{p}_2 \]  

Where \( \hat{w} \), \( \hat{r} \) represent the proportional change in wage rate and the interest rate; \( \hat{p}_1 \) and \( \hat{p}_2 \) are the proportional change in good one and two, \( ij \)'s represent the income share of \( i \) in sector \( j \).

Hence,

\[ \frac{1}{\theta_{L1} - \theta_{L2}} = \hat{r} \]  
\[ \hat{w} - \hat{r} = \frac{1}{\theta_{L1} - \theta_{L2}} (\hat{p}_1 - \hat{p}_2) \]  

The difference between \( \theta_{L1} \) and \( \theta_{L2} \) is proportional to the difference in factor intensities; it is readily seen that, given \( \hat{p}_1 - \hat{p}_2 \), the more different are the factor intensities, the smaller will be the change in the wage-rental ratio.

In their original paper, the emphasis is put on the two-good-two-

\[25\] The following expressions, which have been widely used, originate from Jones, see R. W. Jones, "The Structure of Simple General Equilibrium Model," *Journal of Political Economy*, 73(1965):557-572.
factor case; a number of authors have already extended the case where there are many factors and many goods.\textsuperscript{26} Jones clarifies the Stolper-Samuelson Theorem with an algebraic version of a general equilibrium model. \textsuperscript{27} Jones shows that the change in factor prices induced by the change in product price is proportionally more than the change in the product price; or,

\[ \hat{w} > \hat{p}_1 > \hat{p}_2 > \hat{r} \]  \hspace{1cm} (4)

Expression (4) implies

\[ \left( \frac{w}{r} \right) > \left( \frac{p_1}{p_2} \right) \]  \hspace{1cm} (5)

Although Expression (4) implies Expression (5), the other way is not generally true; that is, one can not obtain the Stolper-Samuelson type of results from expression (5).

Stolper and Samuelson, in their original paper, implicitly asserts that the imposition of tariffs on a good necessarily increases the domestic price of that good; however, as Metzler points out, this may not be always true.\textsuperscript{28} In fact, Metzler asserts that the tariff might well


\textsuperscript{27} Jones, "Simple General Equilibrium Model."

cause the world price of that country's import to fall relative to exports and the secondary reduction of the world price of the imported good may more than offset the initial primary increase in price due to the imposition of tariffs. More precisely, as Minabe puts it, 29 a tariff may not increase the relative domestic price of imported good, if the foreign elasticity of demand for the country's export is less than 1-k, where k is the marginal propensity to import. Minabe argues that, if the tariff is large, then average elasticity rather than marginal elasticity is appropriate.

The Stolper-Samuelson Theorem is essentially about the change in the marginal productivity induced by the factors movement resulting from the exogenous change in the relative price. For the purpose of this study, technological progress needs to be incorporated into the conventional Stolper-Samuelson Theorem. In the presence of technological progress, the factor that suffers from the disadvantageous factor intensities, will not necessarily suffer a lose in real income. Amano's and Diamond's studies give some hint as to how the welfare implications of factor-intensity changes may be offset by the increase in productivity. 30

The Stolper-Samuelson Theorem with Technological Progress

In Stolper and Samuelson's paper, the production possibility frontier is fixed; the equilibrium point moves along the production possibility frontier when the relative price changes. The change in the factor returns resulting from the change in the relative price is essentially due to the differences in the factor intensities. The conventional form of the Stolper-Samuelson Theorem needs to be modified if the production possibility frontier itself shifts because of factor augmentation or technological progress. In what follows, only the shift caused by the technological change is examined. It is shown that the inclusion of technological progress substantially changes the conventional Stolper-Samuelson Theorem: the factor intensively used in the advancing sector will gain in terms of both goods even if its relative price falls, as long as the price does not fall as much as the advance in productivity; the other factor loses in terms of the static sector but still has some chance to be better off in terms of the advancing sector.

Suppose there are two countries: Country One where technological progress takes place; Country Two, where technology is static. Both countries produce X(1) and Y(2), X being the labor intensive good and Y being the capital intensive good. Under the assumption of fixed endowments and full employment, production functions for the advancing country (Country One) are:

\[ X^S = A \ F (K_1, L_1) \]  \hspace{1cm} (6)
\[ \gamma^s = G(K_2, L_2) \]  

(7)

where subscript \( S \) represents the supply of the goods; \( A \) in Expression (1) represents the factor-neutral technological progress that takes place in Country One's \( X \) sector. Similarly, the production functions for the static country (Country Two) are:

\[ x^s = \mathbf{F}^*(K_1^*, L_1^*) \]  

(8)

\[ y^s = \mathbf{G}^*(K_2^*, L_2^*) \]  

(9)

where an asterisk represents the variable of the static country. The production functions for the same good need not be identical in these two countries.

Assume those production functions are homogeneous of degree one, and suppose perfect competition prevails in the output markets as well as input markets; hence Euler's Rule follows:

\[ pX = wL_1 + rK_1 \]  

or

\[ pAF = wL_1 + rK_1 \]  

(10)

And

\[ G(K_2, L_2) = wL_2 + rK_2 \]  

(11)
where \( p \) is the price of \( X \) in terms of \( Y \); \( Y \) is designated as the numeraire; \( w \) and \( r \) are wage rate and interest rate. Totally differentiate Expression (10), and divide it by \( pA^F \), the following form is obtained:

\[
\hat{p} + \hat{A} + \hat{r} = \theta_1 \bar{K}_1 + (1 - \theta_1) \bar{L}_1 + \theta_1 \hat{r} + (1 - \theta_1) \hat{w}
\]

(12)

where \( \theta_1 \) and \( 1 - \theta_1 \) respectively represent the initial income share of capital and labor in \( X \) of Country One. A "cap" above a variable represents the percentage change of that variable. Considering the fact that in the absence of technological progress the change in output is simply the weighted changes in factor input, the weights being the income shares of factors:

\[
\hat{r} = \theta_1 \bar{K}_1 + (1 - \theta_1) \bar{L}_1
\]

(13)

Factor returns can be expressed in terms of price change and technological change when Expression (13) is substituted into Expression (12):

\[
\hat{p} + \hat{A} = \theta_1 \hat{r} + (1 - \theta_1) \hat{w}
\]

(14)
Totally differentiate Expression (11), it follows by the similar reasoning above, another expression like (14) can be derived for Sector Y:

\[ 0 = \theta_2 \hat{r} + (1 - \theta_2) \hat{w} \quad (15) \]

where \( \theta_2 \) and \( (1 - \theta_2) \) are initial income shares of capital and labor in Y of Country One. The zero on the left-hand side of Expression (15) simply reflects that there is no technological progress in Y and that Y is designated as the numeraire.

Solving Expression (14) and (15) for \( \hat{w} \) and \( \hat{r} \) in terms of \( \hat{p} \) and \( \hat{A} \),

\[
\hat{w} = \frac{-\theta_2}{\theta_1 - \theta_2} (\hat{p} + \hat{A}) \quad (16)
\]

\[
\hat{r} = \frac{1 - \theta_2}{\theta_1 - \theta_2} (\hat{p} + \hat{A}) \quad (17)
\]

Expressions (16) and (17) are the distribution effects of technological progress.

Since that X is labor intensive and Y is capital intensive, \( \theta_1 < \theta_2 \); it follows that
\[ \hat{w} > 0 \quad \text{if} \quad \hat{p} + \hat{A} > 0 \quad \text{or} \quad \hat{r} > 0 \quad \text{if} \quad \hat{p} + \hat{A} < 0 \]  
(18)  
(19)

\( \hat{A} \) is certainly positive at any level of technological progress; \( \hat{p} \) can not be determined unless the whole model regarding the whole economy is solved. Even though \( \hat{p} \) has not yet been determined, Expression (18) and (19) suggest that, as far as this chapter's purpose is concerned, what really matters is the magnitude of \( \hat{p} \): Does it fall more than the technological progress? The welfare effects for the factors depend on whether \( \hat{p} + \hat{A} \) is positive. If it is positive, labor will be better off in terms of the numeraire \( Y \); capital will be worse off in terms of the numeraire.

As argued by Hicks and others, the price of \( X \) tends to fall under "normal" situations if technological progress takes place in Sector \( X \). For our purpose, what we need to see is the effects of \( \hat{p} + \hat{A} \). From Expression (16), \( \hat{w} \) is always larger than \( \hat{p} \) regardless that \( \hat{p} \) is positive or negative, provided that \( \hat{p} + \hat{A} \) is positive; namely, labor will gain not only in terms of \( Y \) but in terms of \( X \) if the consolidated effect of the price change and the technological change is positive.

Now the welfare effects for labor in Country One can be summarized in Proposition One as follows:
Proposition One:

If technology advances in a sector and the price of that good does not fall as much as the technology advances, then the factor intensively used in that sector will be better off in terms of both goods.

The effect for capital in terms of X is ambiguous though:

\[
\hat{r} - \hat{p} = \frac{1 - \theta_2}{\theta_1 - \theta_2} \hat{A} + \frac{1 - \theta_1}{\theta_1 - \theta_2} \hat{p} \quad (20)
\]

Expression (20) can be positive or negative; for \( \hat{r} - \hat{p} \) to be positive the following expression is necessary:

\[
\frac{1 - \theta_2}{1 - \theta_1} < -\frac{\hat{p}}{\hat{A}} \quad (21)
\]

Expression (21) means that, for given factor intensities, the price of X should fall "more" in order to make capital better off in terms of X; or, given certain magnitude of change in the price of X, the factor intensities in both sectors should be very different. The welfare effects for capital can be summarized as Proposition Two as follows:
Proposition Two:

If technology advances in the labor-intensive sector and the price of the labor-intensive good does not fall as much as the technological progress, then capital will unambiguously lose in terms of the capital-intensive good, but has some chance to be better off in terms of the expanding sector.

Those two propositions are not surprising. Given the condition of positive $\hat{p} > \hat{A}$, the difference in factor intensities in both sectors benefit labor but hurt capital; the technological progress in Sector X benefits labor even further, and ameliorates the disadvantageous factor-intensity effect on capital in terms of X.

As far as the factors in the other country are concerned, the expressions similar to Expressions (16) and (17) can be derived by similar procedures:

\[ \hat{w}^* = \frac{-\theta_2^*}{\theta_1^* - \theta_2^*} \hat{p} \]  
\[ \text{Eq. (22)} \]

\[ r^* = \frac{1 - \theta_2^*}{\theta_1^* - \theta_2^*} \hat{p} \]  
\[ \text{Eq. (23)} \]

It is readily seen from Expressions (22) and (23) that the Stolper-Samuelson Theorem directly applies to Country Two, namely
Proposition Three:

If the technology advances in a sector of the other country so as to force down the price of that sector, the factor intensively used in that sector of this country will be worse off in terms of both goods while the other factor will be better off in terms of both goods.

So far, the change in the price of X has not been determined yet. The remainder of this chapter will formulate a complete model from which the change in X's price can be determined and in turn all the variables in the integrated world economy can be derived.

The Complete Model

In the last section, the model was not closed in the sense that the equilibrium price had not been determined. A complete model is needed to determine the change in the price, welfare effects and factor movements.

The supply of X in both countries can be derived from Expressions (6) and (8) as follows:

\[
\begin{align*}
S^S &= \hat{A} \ast \theta_1 \hat{K}_1 + (1 - \theta_1) \hat{L}_1 \\
S^* &= \theta_1^* \hat{k}_1^* + (1 - \theta_1^*) \hat{l}_1^*
\end{align*}
\]

(24) (25)

And the demands for X in both countries are defined as
\[ X^D = p^\varepsilon \vert \eta \]  
(26)

\[ X^{D*} = p^{*\varepsilon} \vert \eta^{*} \]  
(27)

where superscript D indicates demand for X; I indicates income in terms of the numeraire; \( \varepsilon \) is the price elasticity of demand for X and \( \eta \) is the income elasticity of demand for X. Variables without asterisks represent those of Country One; variables with asterisks represent those of Country Two.

 Totally differentiate Expressions (26) and (27), and divide by \( X^D \) and \( X^{D*} \), respectively:

\[ \dot{X}^D = \varepsilon \hat{p} + \eta \hat{\Gamma} \]  
(28)

\[ \dot{X}^{D*} = \varepsilon^{*\hat{p}} + \eta^{*}\hat{\Gamma}^{*} \]  
(29)

Here income can be expressed as

\[ I = w \hat{L} + r \hat{K} \]
\[ I^{*} = w^{*} \hat{L}^{*} + r^{*} \hat{K}^{*} \]

Or, equivalently,

\[ \hat{\Gamma} = (1 - \theta) \hat{\omega} + \theta \hat{\tau} \]  
(30)
\[ \hat{\ell}^* = (1 - \theta^*) \hat{w}^* + \theta^* \hat{r}^* \]  

(31)

where \( \theta \) and \( \theta^* \) represent initial economywide capital shares of capital in Country One and Country Two. Substitute Expressions (30) and (31) into Expressions (28) and (29), changes of demand can be expressed in terms of factor returns:

\[ \hat{X}^D = \varepsilon \hat{p} + \eta [ (1 - \theta) \hat{w} + \theta \hat{r}] \]  

(32)

\[ \hat{X}^{*D} = \varepsilon^* \hat{p} + \eta^* [ (1 - \theta^*) \hat{w}^* + \theta^* \hat{r}^*] \]  

(33)

The market-clearing condition for Sector X is

\[ X^S + X^{*S} = X^D + X^{*D} \]  

(34)

and that of Sector Y is

\[ Y^S + Y^{*S} = Y^D + Y^{*D} \]  

(35)

Suppose the trade is in balance initially; the trade-balance equation for Country One is

\[ pX^S + Y^S = pX^D + Y^D \]  

(36)
that for Country Two is

$$pX^S + Y^S = pX^D + Y^D$$  \hspace{1cm} (37)

From Expressions (34) - (37) and considering Walras Law, the market-clearing condition for $X$ is

$$dX^S + dX^* = dX^D + dX^*$$  \hspace{1cm} (38)

Substituting Expressions (24) (25) (32) and (33) into Expression (38), the market-clearing condition can be rewritten as

$$a_{11} \bar{p} - X^S \theta_1 \bar{K}_1 - X^S (1 - \theta_1) \bar{\ell}_1 - X^* \theta_1 \bar{K}_2^* - X^S^* (1 - \theta_1^*) \bar{\ell}_2^* = c_1$$  \hspace{1cm} (39)

where

$$a_{11} \equiv X^D (\varepsilon + \xi_1 \eta) + X^D^* (\varepsilon^* + \xi_1^* \eta^*)$$

$$c_{11} \equiv \bar{\Lambda} (X^S - X^D \xi_1 \eta)$$

where $\xi_1 = (\theta_1 - \theta_2) / (\theta_1 - \theta_2)$ and is the initial income share of good $X$ in the advancing country.\textsuperscript{31}

\textsuperscript{31} This is proved as follows:

$$\frac{(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)} = \frac{(\theta_1 \xi_1 + \theta_2(1 - \xi_1) - \theta_2)}{(\theta_1 - \theta_2)}$$

$$= \frac{(\theta_1 - \theta_2) \xi_1}{(\theta_1 - \theta_2)} = \xi_1$$
Next, look at the equations that determine the movements of factors through the elasticities of substitution:

\[
\sigma_1 = \left( \hat{K}_1 - \hat{L}_1 \right) / \left( \hat{r} - \hat{w} \right) \quad (40)
\]

\[
\sigma_2 = \left( \hat{K}_2 - \hat{L}_2 \right) / \left( \hat{r} - \hat{w} \right) \quad (41)
\]

\[
\sigma_1^* = \left( \hat{K}_1^* - \hat{L}_1^* \right) / \left( \hat{r}^* - \hat{w}^* \right) \quad (42)
\]

\[
\sigma_2^* = \left( \hat{K}_2^* - \hat{L}_2^* \right) / \left( \hat{r}^* - \hat{w}^* \right) \quad (43)
\]

where \( \sigma_i \) represents the elasticity of substitution in Sector i.

Expressions (40) - (43) can be rewritten as follows by considering the assumption of full employment, and substituting changes in factor return with price change in \( X \), namely Expression (16) (17) (22) and (23), into them:

\[
\sigma_2 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] \hat{p} - \hat{\lambda} \hat{L}_1 + \kappa \hat{K}_1 = - \sigma_2 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] \hat{\Lambda} \quad (44)
\]

\[
\sigma_1 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] \hat{p} - \hat{K}_1 + \hat{L}_1 = - \sigma_1 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] \hat{\Lambda} \quad (45)
\]

\[
\sigma_2^* \left[ \frac{1}{(\theta_1^* - \theta_2^*)} \right] \hat{p} - \hat{\lambda}^* \hat{L}_1 + \kappa^* \hat{K}_1 = 0 \quad (46)
\]

\[
\sigma_1^* \left[ \frac{1}{(\theta_1^* - \theta_2^*)} \right] \hat{p} - \hat{K}_1^* + \hat{L}_1^* = 0 \quad (47)
\]

where \( \hat{\lambda} \) and \( \kappa \) represent \( L_1 / L_2 \) and \( K_1 / K_2 \). Expressions (39) and
(44) - (47) comprise a simultaneous equation system from which five variables can be solved: $\hat{p}$, $\hat{K}_1$, $\hat{L}_1$, $\hat{K}_1^*$, $\hat{L}_1^*$. Once $\hat{p}$ is solved, $\hat{w}$, $\hat{r}$, $\hat{w}^*$ and $\hat{r}^*$ can be solved through Expression (16)(17)(22) and (23); once $K_1$, $L_1$, $K_1^*$ and $L_1^*$ are solved, changes in the production of $X$ and $Y$ in both countries can be solved and then the demand for $X$ and $Y$ can be derived. The whole model becomes

$$AX = C$$

(48)

where $A =$

$$
\begin{bmatrix}
 a_{11} & -X^S\theta_1 & -X^S(1-\theta_1) & -X^S^*\theta^*_1 & -X^S^*(1-\theta^*_1)
 \\
 \sigma_2[1/(\theta_1-\theta_2)] & -l & \kappa & 0 & 0
 \\
 \sigma_1[1/(\theta_1-\theta_2)] & 1 & -1 & 0 & 0
 \\
 \sigma_2^*[1/(\theta_1^*-\theta_2^*)] & 0 & 0 & -l^* & \kappa^*
 \\
 \sigma_1^*[1/(\theta_1^*-\theta_2^*)] & 0 & 0 & 1 & -1
\end{bmatrix}
$$

$$X^* = [\hat{p}, \hat{L}_1, \hat{K}_1, \hat{L}_1^*, \hat{K}_1^*]$$

$$C^* = [c_1, -\sigma_2[1/(\theta_1-\theta_2)]\hat{A}, -\sigma_1[1/(\theta_1-\theta_2)]\hat{A}, 0, 0]$$

The rest of the section solves Expression (48). First find the sign of $A$'s determinant by developing $A$ along the first column and show
its i-th cofactor with \( A_i \)

\[
|A| = \sum_{i=1}^{5} A_i
\]

(49)

where

\[
A_1 = a_{11}(\ell^* - \kappa^*) (\ell - \kappa) < 0 \text{ if } a_{11} < 0
\]

\[
A_2 = - \sigma_2 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] (\ell^* - \kappa^*)X^S < 0
\]

\[
A_3 = - \sigma_1 \left[ \frac{1}{(\theta_1 - \theta_2)} \right] (\ell^* - \kappa^*)X^S \theta_1 \kappa + X^S (1 - \theta_1) l < 0
\]

\[
A_4 = - \sigma_2 \left[ \frac{1}{(\theta_1^* - \theta_2^*)} \right] (\ell - \kappa)X^S^* < 0
\]

\[
A_5 = - \sigma_1 \left[ \frac{1}{(\theta_1^* - \theta_2^*)} \right] (\ell - \kappa)X^S^* \theta_1 \kappa + X^S^* (1 - \theta_1^*) l < 0
\]

It is seen from above that the determinant of \( A \) is negative if \( a_{11} \) is negative. Since \( a_{11} = X^D (\varepsilon + \xi_1 \eta) + X^* D (\varepsilon^* + \xi_1^* \eta^*) \), it follows that \( a_{11} \) is negative if the price elasticities dominate income elasticities adjusted by the expenditure shares in both countries. By Cramer's Rule,

\[
\hat{\rho} = \frac{\Delta_1}{|A|}
\]

(50)

where \( \Delta_1 \) indicates \( A \) with the first column replaced by \( C \). Expand \( \Delta_1 \) along the first column and designate the i-th cofactor as \( \Delta_{1i} \).
\[ |\Delta_1| = \sum_{i=1}^{5} \Delta_{1i} \]

where

\[ \Delta_{11} = c_{11}[(l^* - \kappa^*)(l - \kappa)] > 0 \]

\[ \Delta_{12} = \sigma_2[1/(\theta_1 - \theta_2)] \tilde{A} X^S (l^* - \kappa^*) > 0 \]

\[ \Delta_{13} = \sigma_1[1/(\theta_1 - \theta_2)] \tilde{A} X^S (l^* - \kappa^*) [(1 - \theta_1)l + \theta_1 \kappa] > 0 \]

\[ \Delta_{14} = 0 \]

\[ \Delta_{15} = 0 \]

Since \( c_{11} = \tilde{A}(X^S + \xi_1 X^D) \) and is positive for any level of technological progress, \( |\Delta_1| \) is positive; therefore,

\[
\hat{p} = \frac{|\Delta_1|}{|A|} = \frac{(+)}{(-)} < 0
\]

(51)

The change in the price of \( X \) can be summarized as Proposition

Four as follows:
Proposition Four

The world price of X falls as a consequence of technological progress that takes place in Sector X of one country, if the price elasticity dominates the income elasticity adjusted by the expenditure share in both countries.

As stated earlier, the concern of this chapter is the "consolidated effect" of changes in price and technology; namely, one needs to seek the conditions that determine the sign of \( \hat{p} + \hat{A} \), which is to be derived next.

Since

\[
\frac{|\Delta_1| + \hat{A} |A|}{|A|} = \frac{\hat{p} + \hat{A}}{|A|}
\]

(52)

The denominator on the right-hand side of Expression (52) is negative; for \( \hat{p} + \hat{A} \) to be positive, the numerator at the right-hand side of Expression (52) has to be negative:

\[
|\Delta_1| + \hat{A} |A| \equiv \sum_{i=1}^{5} (\Delta_{1i} + \hat{A} A_i)
\]

where

\[
\Delta_{11} + \hat{A} A_1 = (C_{11} + \hat{A} a_{11})[l^* - \kappa^*] (l - \kappa) < 0 \text{ if } C_{11} + \hat{A} a_{11} < 0;
\]
\[ \Delta_{12} + \hat{\Delta}A_2 = 0; \]
\[ \Delta_{13} + \hat{\Delta}A_3 = 0; \]
\[ \Delta_{14} + \hat{\Delta}A_4 = 0 + \hat{\Delta} (\sim) < 0; \]
\[ \Delta_{15} + \hat{\Delta}A_5 = 0 + \hat{\Delta} (\sim) < 0; \]

therefore, the numerator of Expression (52) is negative and \( \hat{\rho} + \hat{\Delta} \) is positive, if \( C_{11} + \hat{\Delta}a_{11} < 0. \)

Since \( a_{11} = X^D(\varepsilon + \xi_1 \eta) + X^*(\varepsilon^* + \xi_1^* \eta^*) \), \( C_{11} + \hat{\Delta}a_{11} < 0 \) implies that

\[ X^S < |X^D\varepsilon + X^*(\varepsilon^* + \xi_1^* \eta^*)| \quad (53) \]

Up to this point, the conditions that determine the direction and magnitude of change in the price of \( X \) can be summarized as Proposition Five as follows:

**Proposition Five**

The price of \( X \) will fall as a consequence of technological progress that takes place in Sector \( X \), but does not fall proportionally as much as the increase in productivity, if

\[ 1. \left| \varepsilon \right| > \xi_1 \eta \quad \text{and} \quad 1. \left| \varepsilon^* \right| > \xi_1^* \eta^* \]
2. \( X^S < |X^D_\varepsilon + X^*_D(\varepsilon^*_1, \eta^*_1)| \)

The first condition simply says that the price elasticities dominate income elasticities adjusted by the income shares in both countries. It may not be surprising that if the price elasticity of demand for \( X \) is high relative to income elasticity, the price has to fall in order to absorb the increase in production resulting from the technological progress in Sector \( X \). The price of \( X \) may increase if the income elasticities are sufficiently higher than the price elasticities; however, as far as the welfare effects on individual factors are concerned, the results will not change qualitatively if the price of \( X \) increases; what is crucial is: how much does the price of \( X \) fall? This question can be answered as the second condition is examined.

In order to clarify the second condition in Proposition Five, imagine that the price of \( X \) drops proportionally as much as the increase in productivity immediately when the technological progress takes place. Given this situation of "momentary proportional change in the price and productivity", the second condition, or Expression (53), will become clearer if we rewrite it as

\[
X^{S\hat{A}} < |X^D_\varepsilon \hat{\rho} + X^*_D(\varepsilon^*_1 \hat{\rho} + \xi^*_1 \eta^*_1 \hat{\rho})| \quad (54)
\]

The left-hand side of Expression (54) represents the increase in the supply of \( X \) in Country One solely because of the technological progress; the right-hand side represents the increase in demand for \( X \) in both countries, including income effects and substitution effects if
the proportionate change in the price of X is as much as the increase in productivity. If Expression (54) holds, the increase in the demand for X will exceed the increase in the supply of X in the advancing country, and the price of X will be pushed up from the "bottom"; namely, the price of X can not drop as much as the increase in productivity measured in percentage terms. It is noteworthy that the price of X will not necessarily drop further from the "bottom" even if Expression (54) does not hold, because, as will be shown later, the production of X in the static country will fall as long as the price of X falls relatively to Y, so the fact that the increase in the global demand for X falls short of the increase in the production of X in the advancing country alone is not a sufficient condition for the price of X to go down even further. The two conditions in Proposition Five also serve as conditions for the welfare effects of technological progress on the factors summarized in Propositions One to Three. Proposition One to Three can be rephrased as follows:

The welfare effects of technological progress that takes place in the Country One's labor-intensive sector can be expressed with the following two expressions if the conditions in Proposition Five hold:

\[ \hat{p} \sim r < 0 = \hat{p}_y < \hat{w} \]  \hspace{1cm} (55)

\[ \hat{w}^* < \hat{p} < 0 = \hat{p}_y < r^* \]  \hspace{1cm} (56)

Expression (55) says that Country One's labor will unambiguously gain while capital will lose in terms of Y but might gain in terms of X; Expression (56) says that the Stolper-Samuelson Theorem directly
applies to the static country.

The size of the economy is also essential to the changes in welfare. In Expression (54), if the advancing country is a small economy in terms of its production of X, chances are that Expression (54) will hold and therefore the welfare effects summarized in Expression (55) and (56) will hold too. This is not surprising because the price will not fall as much as that in the case where the advancing country is a large economy.

Factor Movements

Factors shift between sectors when technology advances. The factor movements can be determined by the relationship between factor intensities and factor prices. Following the procedures for solving $\hat{p}$, the movements of factors can be derived too. For the advancing country, it can be shown that

$$\hat{K}_1 > 0, \hat{L}_1 > 0$$

(57)

Expression (57) means that, given the condition in Proposition Five, both factors will shift from Sector Y into Sector X, and therefore, Country One will produce more X not only because technological

\[\text{32 A mathematical proof of factor movements can be seen in the appendix following this chapter.}\]
advances in X but because factors move to X. This is so because, if the technology advances more than the price falls, more factors must be employed to equate the marginal revenue and marginal cost. If this country exports X as assumed here, then this type of technological progress is export-biased, and will benefit the other country through worsening commodity terms of trade.

It can be shown that capital moves proportionally more from Y to X than labor, namely,

\[ \dot{K}_1 - \dot{L}_1 > 0 \quad (58) \]

Expression (58) means that, since capital moves proportionally more to X than labor does, Sector X will now be less labor intensive relative to what it used to be. It follows that labor gains in terms of X not only because of technological progress but because of a favorable change in factor intensity in X. The welfare effect for capital in terms of X is ambiguous because capital suffers from a worsening change in factor intensity though it enjoys the technological progress in X as labor does.

Given the assumption of full employment, it follows that

\[ \dot{K}_2 < 0, \dot{L}_2 < 0 \quad (59) \]

and

\[ \dot{K}_2 - \dot{L}_2 > 0 \quad (60) \]
Expression (59) and (60) mean that both factors move away from $Y$, and labor moves more (in percentage) than capital; it follows that Sector $Y$ is now more capital intensive than what it used to be. It is readily seen that why labor gains and capital loses in terms of $Y$ : The factor intensity in $Y$ now turns against capital and in favor of labor.

Since Country Two did not experience technological progress, the resources will shift away from Sector $X$ if the relative price of $X$ falls, and therefore the welfare effects of technological progress that takes place in the other country will be just what the Stolper-Samuelson Theorem shows. This can be explained with the changes in factor intensities. It can be shown that

\[ \hat{k}_1^* < 0, \quad \hat{l}_1^* < 0 \]  \hfill (61)

and

\[ \hat{l}_1^* - \hat{k}_1^* > 0 \]  \hfill (62)

Expression (61) and (62) indicate that labor shifts away from Sector $X$ less than capital does; hence $X$ is even more labor intensive relative to what it used to be. Labor in turn suffers from a worsening change in factor intensity in $X$ and loses in terms of $X$ while capital gains in terms of $X$ for the opposite reason. As far as $Y$ is concerned, it can also be shown that

\[ \hat{l}_2^* - \hat{k}_2^* > 0 \]  \hfill (63)
Expression (63) indicates that, in terms of percentage changes, more labor has shifted into Sector Y than capital does; consequently, Sector Y is more labor intensive relative to what it used to be. Since there is no technological progress in Country Two, changes in factor intensities alone can determine the welfare effects: labor loses in terms of both goods while capital gains in terms of both goods.

Concluding Remarks

As far as the welfare effects of individual factors are concerned, the magnitude, as well as the direction, of price change is important. The price of X will fall as a consequence of technological progress in X, if the substitution elasticities dominate income elasticities adjusted by the income shares in both countries. The critical magnitude of price change is the percentage change in productivity: the welfare effects for the innovating country's factors will change entirely according as whether the price falls more or less than technological progress (in terms of percentage). If the increase in the production of X in the innovating country falls short of the increase in demand for X in both countries induced by the substitution effects and income effects, the price of the good that enjoys technological progress will not drop as much as technology advances.

Given the condition stated above, the labor of Country One will be better off in terms of both goods while capital loses in terms of both goods, if technological progress takes place in the labor-intensive
sector. The welfare effects for factors in Country Two are just the opposite: labor loses, capital gains in terms of both goods. Factors move into X in Country One and move away from X in Country Two. Both sectors in Country One are more capital intensive relative to what they used to be. Labor gains in terms of X not only because of technological progress in X but because of favorable changes in factor intensity; labor gains in terms of Y only because of favorable change in factor intensity in Y. Capital loses in terms of Y because of a worsening change in factor intensity in X; it may gain in terms of X because technological progress may come to a rescue though capital suffers from a worsening change in the factor intensity in X.
References to Chapter Two


Appendix to Chapter Two

This appendix provides a proof for the factor movements and the changes in the factor intensities in both sectors and in both countries.

Notations:

$X^S$: Supply of $X$

$K_i$: Capital Employed in Sector $i$, $i=1(X),2(Y)$

$L_i$: Labor Employed in Sector $i$, $i=1(X),2(Y)$

$\sigma_i$: Elasticity of Substitution of Sector $i$, $i=1(X),2(Y)$

$\theta_i$: Capital's Income Share in Sector $i$, $i=1(X),2(Y)$

$l: L_1/L_2$

$\kappa: K_1/K_2$

(Notations with asterisks represent those of the static country; notation with hats represent the rate of change of the variables.)

I. The Advancing Country

a) Capital Movement

From the discussion in the text,

$$\hat{K} = \frac{\Delta_3}{\Delta A} \hspace{1cm} (A-1)$$
where \(| \Delta_3 | = \)

\[
\begin{bmatrix}
  a_{11} & -x^S \theta_1 & -x^S A & -x^S \theta_1^* & -x^S * (1 - \theta_1^*) \\
  \sigma_2 [1 / (\theta_1 - \theta_2)] & -l & -\sigma_2 [1 / (\theta_1 - \theta_2)] A & 0 & 0 \\
  \sigma_1 [1 / (\theta_1 - \theta_2)] & 1 & -\sigma_1 [1 / (\theta_1 - \theta_2)] A & 0 & 0 \\
  \sigma_2^* [1 / (\theta_1^* - \theta_2^*)] & 0 & 0 & -l^* & \kappa^* \\
  \sigma_1^* [1 / (\theta_1^* - \theta_2^*)] & 0 & 0 & 1 & -1 \\
\end{bmatrix}
\]

\(| \Delta_3 | = \sum_{i=1}^{5} \Delta_{3i} \) \hspace{1cm} \text{(A-2)}

and

\[
\Delta_{31} = a_{11} [(1 / (\theta_1 - \theta_2)) A (l^* - \kappa^*) (l \sigma_1 + \sigma_2)]
\]

\[
\Delta_{32} = -\sigma_2 [1 / (\theta_1 - \theta_2)] [x^S A (l^* - \kappa^*) (\sigma_1 \sigma_2 (1 / (\theta_1 - \theta_2)) + 1)]
\]

\[
\Delta_{33} = \sigma_1 [1 / (\theta_1 - \theta_2)] x^S \hat{A}(l^* - \kappa^*) [\sigma_1 \sigma_2 (1 / (\theta_1 - \theta_2)) - l]
\]

\[
\Delta_{34} = -\sigma_2^* [1 / (\theta_1^* - \theta_2^*)] [1 / (\theta_1 - \theta_2)] x^S \hat{A} (\sigma_1 l + \sigma_2) < 0
\]

\[
\Delta_{35} = \sigma_2^* [1 / (\theta_1^* - \theta_2^*)] [1 / (\theta_1 - \theta_2)] x^S \hat{A}
\]

\[(-\sigma_1 l - \sigma_2)(l^* (1 - \theta_1) + \theta_1 \kappa^*) < 0\]
\[ \sum_{i=1}^{5} \Delta_{3i} = \hat{A}(l^* - \kappa^*)[1/(\Theta_1 - \Theta_2)](\sigma_2 + l \sigma_1)(a_{11} - XS) + \Delta_{34} + \Delta_{35} < 0 \], therefore,

\[ \hat{K} > 0 \text{ if } a_{11} + XS < 0 \]

b) Labor Movement

Similarly,

\[ \hat{L} = \frac{\Delta_2}{|A|} \quad \text{-------------------(A-3)} \]

\[ |\Delta_2| = \begin{vmatrix}
    a_{11} & -XS\hat{A} & -XS(1-\Theta_1) & -XS^*\Theta_1^* & -XS^*(1-\Theta_1^*) \\
    \sigma_2[1/(\Theta_1 - \Theta_2)] & -\sigma_2[1/(\Theta_1 - \Theta_2)]\hat{A} & \kappa & 0 & 0 \\
    \sigma_1[1/(\Theta_1 - \Theta_2)] & -\sigma_1[1/(\Theta_1 - \Theta_2)]\hat{A} & -1 & 0 & 0 \\
    \sigma_2^*[1/(\Theta_1^* - \Theta_2^*)] & 0 & 0 & -l^* & \kappa^* \\
    \sigma_1^*[1/(\Theta_1^* - \Theta_2^*)] & 0 & 0 & 1 & -1
\end{vmatrix} \]

\[ |\Delta_2| = \sum_{i=1}^{5} \Delta_{2i} \quad \text{-------------------(A-4)} \]
\[ \Delta_{21} = a_{11} \left[ 1/(\theta_1 - \theta_2) \right] \Lambda (l^* - \kappa^*) (\sigma_2^{+} \kappa \sigma_1) \]

\[ \Delta_{22} = \sigma_2 \left[ 1/(\theta_1 - \theta_2) \right] X^S \Lambda (l^* - \kappa^*) \left[ (1 - ((1 - \theta_1)/(\theta_1 - \theta_2)) \sigma_1 \right] \]

\[ \Delta_{23} = \sigma_1 \left[ 1/(\theta_1 - \theta_2) \right] X^S \Lambda (l^* - \kappa^*) (-\kappa - \sigma_2 ((1 - \theta_1)/(\theta_1 - \theta_2)) \sigma_1 \]

\[ \Delta_{24} = -\sigma_2 \left[ 1/(\theta_1 - \theta_2) \right] X^S \Lambda (l^* - \kappa^*) (-\kappa - \sigma_2 ((1 - \theta_1)/(\theta_1 - \theta_2)) < 0 \]

\[ \Delta_{25} = \sigma_2 \left[ 1/(\theta_1 - \theta_2) \right] X^S \Lambda (l^* - \kappa^*) (-\kappa - \sigma_2 ((1 - \theta_1)/(\theta_1 - \theta_2)) \sigma_1 \]

\[ |\Delta_2| = \left[ 1/(\theta_1 - \theta_2) \right] (l^* - \kappa^*) \Lambda (l^* - \kappa^*) (a_{11} - X^S) \Delta_{24} \]

\[ + \Delta_{25} < 0 \]

therefore

\[ \tilde{L} > 0 \]

c) Changes in Factor Intensities

\[ \tilde{K}_1 \quad \hat{L}_1 = \]

\[ = \frac{1}{|A|} \left[ \Lambda (1/(\theta_1 - \theta_2)) (l^* - \kappa^*) (a_{11} - X^S) \sigma_1 (l - \kappa) \right. \]

\[ - \sigma_2^{+} \sigma_1 (l - \kappa) > 0 \]
\[ \hat{K}_2 - \hat{L}_2 = \]
\[
\frac{1}{|A|} \left\{ \hat{A} \left( \frac{1}{(\theta_1 - \theta_2)} \right) \left( l_1 - \kappa \right) \right\} \sigma_2 (\kappa - \lambda) \\
+(1/(\theta_1 - \theta_2)) (1/(\theta_1 - \theta_2 ^*)) \left\{ \sigma_2 ^* \sigma_2 (\kappa - \lambda) \\
+(l^* \theta_1 ^* + \kappa ^*(1 - \theta_1 ^*)) \sigma_1 ^* \sigma_2 (\kappa - \lambda) \right\} \}
> 0
\]

II. The Static Country

a) Capital Movement

\[ \hat{K}^* = |\Delta_5| / |A| \]

where \[ |\Delta_5| = \]
\[
\begin{bmatrix}
 a_{11} & -X^S(1-\theta_1) & -X^S\theta_1 & -X^S*(1-\theta_1^*) & X^S\hat{A} \\
\sigma_2[1/(\theta_1 - \theta_2)] & -\lambda & \kappa & 0 & -\sigma_2[1/(\theta_1 - \theta_2)]\hat{A} \\
\sigma_1 [1/(\theta_1 - \theta_2)] & 1 & -1 & 0 & -\sigma_1 [1/(\theta_1 - \theta_2)]\hat{A} \\
\sigma_2 ^*[1/(\theta_1 ^* - \theta_2 ^*)] & 0 & 0 & -\lambda ^* & 0 \\
\sigma_1 ^*[1/(\theta_1 ^* - \theta_2 ^*)] & 0 & 0 & 1 & 0 \\
\end{bmatrix}
\]

\[ |\Delta_5| = \sum_{i=1}^{5} \Delta_{5i} \]  ____________________________\textsuperscript{-(A-5)}
and

\[ \Delta_{51} = 0 \]

\[ \Delta_{52} = 0 \]

\[ \Delta_{53} = 0 \]

\[ \Delta_{54} = -\sigma_2^{*}[1/(\theta_1^{*}-\theta_2^{*})] \{[1/(\theta_1-\theta_2)] (1-\theta_1)X^S*\hat{A} (\sigma_1\kappa+\sigma_2) \\
-\lambda X^S\hat{A}(1+\theta_1\sigma_1(1/(\theta_1-\theta_2))) \\
+X^S\hat{A}(-\kappa+\theta_1\sigma_2 (1/(\theta_1-\theta_2)))\} \]

\[ \Delta_{55} = -\sigma_2^{*}[1/(\theta_1^{*}-\theta_2^{*})] \{[1/(\theta_1-\theta_2)] (1-\theta_1)X^S*\hat{A}(\sigma_1\kappa+\sigma_2) \\
+\lambda l^{*} X^S*\hat{A} (1+\theta_1\sigma_1(1/(\theta_1-\theta_2))) \\
+ X^S*\hat{A} l^{*} (-\kappa+\theta_1\sigma_2 (1/(\theta_1-\theta_2)))\} \]

\[ |\Delta_5| = 5 \sum_{i=1}^{5} \Delta_{5i} \]

\[ =X^S\hat{A}(1/(\theta_1^{*}-\theta_2^{*}))(\sigma_2^{*}+\sigma_1^{*}l^{*})[(1-\theta_1)(1/(\theta_1-\theta_2))(\sigma_2^{*}+\sigma_1^{*}\kappa) \\
+(\lambda-\kappa)+\theta_1(1/(\theta_1-\theta_2))(\lambda \sigma_1^{*}+\sigma_2^{*})] > 0 \]

therefore,

\[ \hat{\kappa}^* = |\Delta_5| / |A| < 0 \]
b) Labor Movement

Similarly,

\[ \mathcal{L}^* = \frac{|\Delta_4|}{|A|} \]

\[ |\Delta_4| = \begin{bmatrix}
    a_{11} & -x^S(1-\theta_1) & -x^S \theta_1 & x^S \hat{A} & -x^S \theta_1^* \\
    \sigma_2[1/(\theta_1-\theta_2)] & -\lambda & \kappa & -\sigma_2[1/(\theta_1-\theta_2)]\hat{A} & 0 \\
    \sigma_1[1/(\theta_1-\theta_2)] & 1 & -1 & -\sigma_1[1/(\theta_1-\theta_2)]\hat{A} & 0 \\
    \sigma_2^*[1/(\theta_1^*-\theta_2^*)] & 0 & 0 & 0 & \kappa^* \\
    \sigma_1^*[1/(\theta_1^*-\theta_2^*)] & 0 & 0 & 0 & -1
\end{bmatrix} \]

\[ |\Delta_4| = \sum_{i=1}^{5} \Delta_{4i} \]

\[ = x^\hat{A}[(\lambda-\kappa) + (1-\theta_1)(1/(\theta_1-\theta_2))(\kappa \sigma_1 + \sigma_2) + \theta_1(1/(\theta_1-\theta_2))(\sigma_2 + \lambda \sigma_1)] \\
(1/(\theta_1^*-\theta_2^*))(\sigma_2^* + \kappa^* \sigma_1^*) > 0 \]

therefore,

\[ \mathcal{L}^* = \frac{|\Delta_4|}{|A|} < 0 \]
c) Changes in Factor Intensities

\[ \hat{L}_1^* - \hat{K}_1^* = \frac{1}{|A|} \left\{ X^S \hat{A} \left( \frac{1}{\theta_1^* - \theta_2^*} \right) \sigma_1^* (\kappa_1^* - \ell_1^*) \right\} \]

\[ = \frac{1}{|A|} \left\{ \left[ (l - \kappa) + (1 - \theta_1)(1/(\theta_1 - \theta_2))(\kappa \sigma_1 + \sigma_2) + \theta_1(1/(\theta_1 - \theta_2))(\sigma_2 + \ell \sigma_1) \right] \right\} \]

\[ > 0 \]

\[ \hat{L}_2^* - \hat{K}_2^* = \frac{1}{|A|} \left\{ X^S \hat{A} \left( \frac{1}{\theta_1^* - \theta_2^*} \right) \sigma_2^* (\kappa^* - \ell^*) \right\} \]

\[ = \frac{1}{|A|} \left\{ \left[ (l - \kappa) + (1 - \theta_1)(1/(\theta_1 - \theta_2))(\kappa \sigma_1 + \sigma_2) + \theta_1(1/(\theta_1 - \theta_2))(\sigma_2 + \ell \sigma_1) \right] \right\} \]

\[ > 0 \]
CHAPTER THREE

TECHNOLOGY AS A PUBLIC GOOD
AND ITS IMPLICATIONS IN
LABOR MIGRATION

The theory of public goods is one of P. A. Samuelson's contributions in economics and a number of economists have extended Samuelson's theory to incorporate the case in which technology is treated as a public good.¹

This chapter first derives the efficiency criterion for the provision of innovating activities in a Ricardian model with a continuum of goods, and then determines the production of new technology; once the level of technology is determined, the welfare implications of technological progress and technology dissemination can be inferred by the analytical framework developed by Dornbusch, Fisher, Samuelson.2

In what follows, the literature regarding technology as a public good is surveyed, and some comments regarding the Krugman framework are made for this chapter is essentially an extension of Krugman's work. Then the efficient level of innovating activities as well as the new technology is determined by explicitly introducing the cost of innovative activities in terms of the labor used in those activities. Since the creation of new technology is costly, the innovator has incentives to charge royalties to license the technology which, in turn, brings in the regulatory issues of technological dissemination.3

Another feature of this section is the biasedness of technological progress. As pointed out by Hicks and discussed in Chapter Two of this dissertation, the biasedness of technical change is critical to the welfare effects to a country as a whole and to individual factors. In fact, the biasedness of technology is a crucial issue in technology.

---


3 Regulatory issues will be treated in Chapter Four of this dissertation.
transfer, for certain type of biasedness could make technology transfer harmful to the donor country; this is the main theme in Krugman's model. By defining "productivity elasticity of technology", the biasedness of technology can be better handled.\textsuperscript{4}

In the last section of this chapter, the model is applied to study the issue of international population migration. When technological progress is fixed exogenously, an increase in population is generally disadvantageous because the relative wage rate of the innovating country is reduced; this is no longer true if technology is a public good provided at the optimal level. As more people use the technology if the labor size is larger, it pays to devote more resource to innovating activities and to produce more new technology; hence general productivity increases as more population moves in. On the other hand, however, the relative wage rate tends to decrease as the labor size increases. An optimal level of labor size can be derived when the gains from increased productivity is offset by the losses of the balance-of-trade effect.

\textbf{Literature Review}

Samuelson's contributions on what he calls "collective consumption goods", though not directly related to the innovative activities, are the

\textsuperscript{4} "Productivity elasticity of technology" is defined as the percentage change in productivity of other goods when there is one percent change in the level of technology.
cornerstone for the study of intermediate public inputs. His major
ctribution is the determination of the optimal conditions for the
provision of public goods: The technical substitution rate between
private goods and the public good should be equal to the sum of the
marginal rate of substitution between the public good and the private
good for all consumers of the public good; namely,

$$\sum_{i=1}^{s} \frac{u^i_j}{u^i_r} = \frac{F_j}{F_r}$$

(1)

where $s$ represents the number of the public goods' consumers; $u_j$ and
$u_r$ are the marginal utility of the private good and the marginal utility
of the public good; $F_j/F_r$ represents the marginal rate of technical
substitution between the private good and the public good. This
condition and those characterizing the optimal state of the provision of
public goods are then referred to as "Samuelson Conditions".

Samuelson also argues that the decentralizing pricing system that
determines the optimal provision level of the public good does not
exist because of the "free-rider" problem. However, the value of the
public intermediate input to the producers can be revealed by the
market. That is, with competitive factor and product markets and
constant return to scale, total revenue net of payments to other
productive factors should be interpreted as the value of the public

---

5 P. A. Samuelson, "The Pure Theory of Public Expenditure," *Review of
intermediate input because overall profits are zero.⁶ If the public
good is unpriced, however, this approach is no longer appropriate for
in this case total revenue will be dissipated by factors other than the
intermediate public input if the market is competitive; or some
revenue will wind up being the profit if the market is monopolized.

The imputation of the value of the public intermediate input
provides the information on which the taxation of that public good can
be based. The imposition of royalties on the users is possible if the
public intermediate good is considered a new technology.

Kaizuka explicitly derives the conditions parallel to those by
Samuelson to show the optimal provision level of public intermediate
inputs;⁷ namely,

\[
\sum_{j=1}^{n} \frac{\partial F_j}{\partial X_{n+i}} = \frac{1}{\sum_{j=1}^{n} \frac{\partial F_j}{\partial V_{rj}} \frac{\partial F_{n+i}}{\partial V_{r,n+i}}} \tag{2}
\]

where \( F_j \) is the production functions for the private goods; \( F_{n+i} \) are
the production functions for the public goods, and \( V_{rj}, V_{r,n+i} \) are the
resources used in the production of private goods and public goods.
Expression (2) will be referred to as the Samuelson-Kaizuka condition
because of the resemblance with the Samuelson conditions.

⁷ K. Kaizuka, "Public Goods and Decentralization of Production," Review of
Economics and Statistics, 47(1965):118-20. He also derives the optimal condition
for the production of public international goods that can be used as inputs in
the production of other private goods as well as final consumption goods.
Kaizuka's condition is derived through the maximization of production; Sandmo derives the similar conditions through a general equilibrium system. He also shows that the rule for optimal production of the collective factors is that the production of the public goods should be carried up to a point where its value of marginal product should be equal to the private factor price. This shadow price turns out to be the basis for charging royalties of new technology.

Connolly treats new technology as an intangible good that is traded between two countries. He first points out that, in autarky, the efficiency conditions for the production of induced technology is that resources must be diverted to R&D sector up to the point where the extra gain in increased production due to the new technology is equal to the fall in production in other goods resulting from the diversion of resources to innovative activities. This is simply a version of the Samuelson-Kaizuka condition. However, when the technology is open to trade, there are incentives for the innovating country to produce technology beyond the level that is optimal in autarky, because now the innovating country can be compensated by the other country through royalty payments. For the innovating country, another favorable effect of trading in technology is that the production of the adopting country increases as a consequence of the acquired new technology; the terms of trade must turn to favor the innovating country. Thus, the innovating country benefits from three elements

---

when technology is traded: a) The production of the innovating country decreases; b) The production of the recipient country increases; c) The royalties will be collected. It follows that the subsidies for the production for such a monopolistic new technology will make the innovating country better off and therefore are desirable.

In his model, since each country produces only one good, any progress has to be "export-biased" in Hicks' sense; therefore, free technology transfer is also beneficial to the donor country because of the terms of trade will turn to benefit the donor country. Connolly realizes in the latter part of his paper that this conclusion may not be true if the specialization is incomplete. In fact, free transfer is not always beneficial to the donor country under complete specialization as long as the production range can expand.

In the last part of his paper, Connolly extends his discussions to the sector-biased technological progress. For this type of technological progress to shed new light, the specialization should not be complete; otherwise, it degenerates to be a one-sector model. In this case, the discussion is similar to Hicks' Lecture, and Connolly concludes that the "export-biased" type of technological progress might have to be taxed because the terms of trade may change adversely.

The Ricardian model with a continuum of goods developed by Dornbusch, Fischer, Samuelson turns out to be an ingenious device for analyzing technological progress.\textsuperscript{10} In their model, specialization is

\textsuperscript{10} See D-F-S, "Continuum Goods" and Krugman"Technology Gap". 
complete; the production pattern is determined by the interplay between the wage rate differences and productivity differences. One implication of the model where the production choice is limited and the specialization is complete is that the technological progress has to be export-biased and so changes in commodity terms of trade work to the disadvantage of the innovating country. In D-F-S-K's model, this is no longer true because the production range can expand when the technology of the country advances. With an expanded production range, some previously imported goods may become exported goods and vice versa. The innovating country reschedules its resources to take over some "foreign goods" and technological progress may be import-biased; therefore, it is possible that the rest of the world might be hurt as a consequence of technological progress. To see the implication of expandable production range, imagine the production range is limited. Then the resources are confined in a fixed range; the resources may become so abundant that the price of the resource is reduced by the technological progress. Put another way, the innovating country has to produce "too much" of a limited variety of goods so that the commodity terms of trade may turn adversely so as to hurt the innovating country itself.

Another feature of the D-F-S-K framework is that the spill-over effects can be expressed conveniently as the difference between the change of productivity and the change of wage rate.

The main limitations of D-F-S-K are: first, the source of technological is unexplained. The exogeneity of technological progress imparts a perception that technology is costless and therefore the
more the better. Technology, however, is usually a consequence of innovative activities which require resources too. The economy might end up being worse-off if the resources are not used in the production of technology wisely. Second, the demand functions take the Cobb-Douglass form and are identical not only across the individuals within the country but across the countries too. It it sometimes desirable to simplify the demand side so as to highlight the effects of technological progress on the supply side. However, with identical consumption propensities in both countries, the transfer payments and transfer of purchasing power, say royalty payments, will not change the terms of trade and production patterns unless the nontradable sector exists. Third, The biasedness of technological progress, as shown in D-F-S-K is crucial to the welfare implications of technological progress; however, they analyze only innovations biased toward "high-tech" industries. The cases in which technological progress is biased to low-tech are not examined.\textsuperscript{11}

Manning and McMillan's paper focuses on characterizing the production possibility frontier in the presence of innovative activities.\textsuperscript{12} They show that the royalties for using the newly created technology should be proportional to the output level according to Lindahl pricing system. They then put the technology structure into the context of international trade and come up with the criteria for the

\textsuperscript{11} D-F-S did not explain the source of biasedness; Krugman did, but only the "high-tech-biasedness" is explained and examined.

determination of specialization.

Using the Samuelson-Kaizuka condition, Pugel derives the optimal level of innovative activities and shows that the labor devoted to efficient production of technology should be proportional to the size of the labor force, provided that the productivity elasticities of new technology is identical across industries.\textsuperscript{13} He also derives the optimal level of the innovative activities in the case that the world as a whole is taken into consideration.\textsuperscript{14} In this case, more technology will be produced and the global income increases. He finds that the welfare of the innovating country is maximized if appropriate royalties can be charged. On the other hand, the recipient country prefers lower royalties; however, free technology transfer may not to the best interests of the recipient country if royalties cause more innovations which in turn benefit the recipient country as well as the innovating country.

Technology as a Public Good

It is assumed that there is a continuum of goods, and there are two countries: the advanced country and the developing country; each country is potentially able to produce a continuum of goods with labor only, and the production functions for all goods other than technology


\textsuperscript{14} This point is also made by Connolly, see Connolly, "Induced Technology."
where $Y_i$ is the output of the $i$-th good; $t$ is the amount of new technology that aids in the production through function $a_i$; $L_i$ is the labor used in the production of industry $i$. From now on, the variables without asterisks represent that of the advanced country; those with asterisks represent that of the developing country.

The new technology is produced in the following fashion:

$$t = f(L_T) = f' * L_T$$

where $L_T$ represents the labor used in the production of new technology. For the moment, assume that only the advanced country is able to carry out the innovative activities. The production structure is completed by the resource constraint:

$$\sum_{i=1}^{m} L_i + L_T = L$$

---

From Expression (3), $1/a_i$ can be interpreted as the unit requirement of labor for industry $i$ in the advanced country and $1/a_i^*$ is that of the developing country.\textsuperscript{16} Suppose the industries are so indexed that the advanced country's leading margin in the productivity becomes larger as the industry index becomes higher; namely,

$$a_1/a_1^* < \cdots < a_z/a_z^* < \cdots < a_m/a_m^*$$ \hfill (6)

Moreover, it is convenient if the industries are indexed by the initial productivity gap; that is \textsuperscript{17}

$$a_z/a_z^* = z, \ z \in [0,m]$$ \hfill (7)

Let $w$ and $w^*$ represent the wage rates that prevail in the advanced country and the developing country respectively. For each good to be produced in both countries with equal costs, the following form should hold:

$$w/a_z = w^*/a_z^*$$ \hfill (8)

\textsuperscript{16} The formulation of the model from here is adapted from Krugman's model in which the technological progress is exogenous. See Krugman, "'Technology Gap' Model".

\textsuperscript{17} The index can then be treated as a cardinal number rather than an ordinal number.
\[ \omega \equiv \frac{w}{w^*} = \frac{a_z}{a_z^*} \]  

(9)

Depict Expression (9) in a \( \omega - z \) space, and name the relationship as Schedule A, as shown in Figure 1.

![Figure 1](image-url)

Schedule A can be expressed as

\[ \omega = \alpha(t) + \beta(t) z \]  

(10)
where \( \alpha(t) \) represents the advanced country's leading margin in productivity for its least advantageous industry;\(^{18}\) \( \beta(t) \) is initially unitary by definition. Note that \( \alpha(t) \) and \( \beta(t) \) are functional on the technology level; namely, Schedule A will change its position as well as slope when technology changes.

In order to highlight the role of technology, the demand side is simplified by the assumption of Cobb-Douglass demand functions. Demand functions are identical not only across all industries but across countries. One implication of such a demand structure is that each commodity takes up a constant expenditure share:\(^{19}\)

\[
b_i = \frac{p_i C_i}{I}
\]

\[
b_i = b_i^* \quad \quad \quad \quad \quad \quad (11)
\]

\[
m \sum_{i} b_i = 1
\]

where \( b_i \) is the expenditure share of industry \( i \); \( p_i \) is the price of good \( i \) which is identical throughout the world; \( I \) is the income (of the advanced country).

Let \( S(Z) \) represents the share of the global income that is spent on

\(^{18}\) The advanced country may have disadvantage in this industry; in this case, \( \alpha(t) \) is less than one.

\(^{19}\) This rules out the changes in the terms of trade resulting from the differences in the propensities to consume.
the goods produced in the developing country:

\[
S(z) = \int_{0}^{\overline{z}} b_z \, dz
\]  

(12)

and \( \overline{z} \) represents the "marginal good" that can be determined through the interplay of the supply side and the demand side.

Following the Samuelson-Kaizuka condition, the optimal condition for the production of new technology is

\[
\sum_{i=z}^{m} \frac{a_i'}{a_i} = \frac{1}{f'}
\]

(13)

The optimal level of innovative activities can be solved through the production function of the new technology, resource constraint and the optimal condition (13)

\[
L_T = \frac{t}{f} = \int_{i=z}^{m} \frac{t}{a_i} \, L_i
\]

Define \( ta_i' / a_i \) as the productivity elasticity of technology for the industry \( i \), \( \eta_i \) (for simplicity, \( \eta_i \) is assumed a constant for all technology level), then \( L_T \) can be expressed as
\[
L_r = \frac{\int \eta_i \ell_i}{1 + \int \eta_i \ell_i}
\]

where \( \ell_i \) is the labor share used in industry \( i \). Express (13) can be simplified if \( \eta_i = \eta_j \) for all \( i, j \in [0, m] \):

\[
L_r = \frac{\eta}{1 + \eta}
\]  

(14)

where \( \eta \) represents the aggregate productivity elasticity of new technology to all industries.

From Expression (14), it is seen that the optimal innovative activities are proportional to the size of the labor force if the new technology makes the same contribution to all industries in terms of percentage; this suggests that more new technology will be produced if the labor force is larger. It follows that the general productivity as well as the relative wage rate will be higher if the labor force is larger; therefore, the migration of population can be integrated into the determining process of the technology production.

The biasedness of the newly created technology plays a very crucial role in the impact of technology creation and transmission. Suppose the productivity elasticities of new technology are identical across the industries, then the new technology is biased to the high-index industries. This can be shown in the Figure 2.

For the productivity elasticities to be identical across all industries,
assuming the developing country is static in its productivity, $EF / FG$ should be equal to $E'F'/E'F'$. It follows that, for uniform productivity elasticity, the advanced country's leading margin in the high-index industries will be larger. This, in fact, is essentially Krugman's "widening" case.\textsuperscript{20} Next, consider the condition that the new technology is industry-neutral in the sense that Schedule $A$ will shift upward in a parallel fashion.

By virtue of expression (10), Schedule $A$ can be expressed in terms of the productivity elasticities of technology. Differentiate Expression (10) with respect to $t$ and rewrite it in terms of $\eta_i$:

\textsuperscript{20} Krugman, "Technology Gap' Model".
\[
\frac{d\omega}{dt} \quad t \quad \frac{d\alpha}{dt} \quad \frac{d\beta}{dt} \quad t
\]

\[
\left[ \begin{array}{l}
\alpha + \beta z
\end{array} \right] \cdot \quad \frac{d\eta_i}{dt} = \frac{d\alpha}{dt} \quad \frac{t}{\alpha + \beta z}
\]

\[
= \frac{d\alpha}{dt} \quad \frac{t}{\alpha} \quad \frac{\alpha}{\alpha + \beta z}
\]

\[
= \varepsilon_0 \quad \frac{t}{\alpha + \beta z}
\]

(15)

where \(\varepsilon_0\) is the productivity elasticity of the industry in which the advanced country has least advantages. Depict Expression (15) in the \(\eta_i - z\) space, the locus representing a parallel shift of Schedule A is a downward sloping curve. The loci characterized by Expression (15) are a family of curves represented by \(EE\) in Figure 3, \(\varepsilon_0\) being the parameter. It can be shown that if the loci present a family of flatter curves, Schedule A would shift upwards in a way that the advanced
country's leading margin in productivity becomes wider for the high-tech industries; likewise, if the loci present a family of steeper curves, the advanced country will pick up more in industries in which it has less advantage in the productivity margin.

The Equilibrium Relative Wage Rate and Specialization

Since the labor market is assumed to be competitive, the wage rate paid to the labor used in the production of new technology should be equal to that paid to the rest of the labor; therefore, the trade-balnce equation will be the same as that in Krugman's article: 21

\[ wL = [1 - S(z)] [wL + w^*L^*] \]

(16)

The left-hand side of Expression (16) represents the income of the innovating country, which is equal to the share of the global income spent on the goods produced by the innovating country. Solve the relative wage rate from Expression (16) and we obtain

\[ \omega = \frac{L^*}{L} \frac{[1 - S(z)]}{S(z)} \]

(17)

Expression (17) will be designated as Schedule B. Putting together

21 Krugman, "Technology Gap".
Expression (10) (Schedule A), Expression (17) (Schedule B) and Expression (14) (the optimal level of innovative activities), the equilibrium relative wage rate ($\bar{\omega}$), marginal good ($z$), and the optimal
labor used in the production of the new technology can be solved.\footnote{22} Depict the equilibrium values in Figure 4.

In Figure 4, $A$ and $A'$ represent Schedule $A$ before and after the innovative activities are carried out and the productivity elasticities of \footnote{22} If the productivity elasticities are different for different industries, the labor shares used in all industries need to be obtained through the production structure first before solving the optimal level of labor used in innovative activities.
technology are assumed identical across the industries. Figure 4 is actually Krugman's "widening" case\textsuperscript{23} except that the technological progress is now determined along all other variables in the economy.

As the "widening" case suggests, both countries will be better off; the shaded area represents the spill-over effects for the developing country. If the low-index industries are so much more sensitive to the new technology that the technology is actually biased to the

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure5.png}
\caption{Figure 5}
\end{figure}

\textsuperscript{23} Krugman, "'Technology Gap'".
low-index industries, the technological progress may be good or bad to the developing country. This is corresponding to Hicks' "import-biased" case, and therefore, the commodity terms of trade may turn against to the rest of the world if the gains weighted by expenditure shares (shade area I) is less then the loss weighted by expenditures (shaded area II) in Figure 5.

The analysis outlined above for the advanced country can also be applied to the developing country without any substantive modifications. In the case of constant productivity elasticities of technology, the developing country will make more progress in the "high-tech" sector, as shown in Figure 6, which is equivalent to Krugman's "catching up" case except for the endogeneity of technological progress.

In this case, although the developed country can import cheaper mid-index goods (the gains are represented by the shaded area I), the low-index goods will be more expensive in terms of the wage rate of the advanced country (the losses are represented by the shaded area II). The advanced country may not be better off because of the spill-over effects from the developing country. Krugman considers this may provides an argument for technology protectionism.

If the developing country makes more progress in its conventional sector, as shown in Figure 7, the spill-over effects (represented by the

---

24 Hicks, "Lecture".

25 The implications of industry-neutral type of technological progress are pretty much similar to those of the high-index biased technological progress and will not be elaborated here.
shaded area) will definitely make the developed country better off.

Up to this point, some conclusions regarding technological progress can be drawn. First, technological progress biased to what the innovating country has been good at will benefit both countries while the technological progress biased to what the other country is good at might make the other country worse off. Second, the advanced country will be willing to transfer technology without charging royalties to the developing country if the technology is low-index biased. Third, some royalties may have to be charged to the developing country to compensate the innovating country if the new technology is biased to high-index industries.

The Optimal Population Migration

In the case where the technological progress is exogenously fixed, factorial terms of trade turn against the country where the population increases. Therefore, anyone who gains by moving to anywhere else must make some other people worse off. In the case of endogenous technological progress which bears the characteristics of public goods, the movements of labor force may make both sides better off and it is possible to determine the optimal distribution of the population.

Owing to the externality of technology assumed here, the newly

26 D-F-S. "Continuum Goods."
27 This is a Pareto optimality of labor migration under the situation where transfer payments are not possible; if compensational transfer payments are allowed, the optimal point would be where the wage rate are equalized across countries.
Figure 6

Figure 7
created technology can be used by any one within the country, and as Expression (14) shows, the production of new technology is proportional to the labor force; therefore, more technology will be produced if the labor size is larger. Productivity and the relative wage rate resulting from the increases productivity will be higher if a country’s population increases. However, there is a negative aspect of the analysis. As shown in D-F-S-K, the increases of population will shift Schedule B in the direction that decreases the relative wage rate of the country into which the population moves. Hence, there are two counteracting forces at work: one is the productivity effect which benefits the country with increasing population; the other is the gains-from-trade effects that tend to reduce the relative wage rate of the country with increasing population. The issue therefore boils down to how much can the world as a whole benefit from reshuffling the population between countries?

To answer these questions, substitute Expression (14) (the optimal level of innovative activities) into Schedule A (Expression 10), and Expression (17) into Schedule B, and take derivative with respect to L. Notice that \( dL = -dL^* \) and the following equation system is obtained:

\[
\begin{pmatrix}
1 & -\beta \\
L^*S'(z) & 1 \\
1 & \cdots \\
L^2S(z)
\end{pmatrix}
\begin{pmatrix}
d\omega \\
dz
\end{pmatrix}
= \begin{pmatrix}
(\alpha'z + \beta'zL) \\
(L + L^*)[1 - S(z)] \\
-L^2S(z)
\end{pmatrix}
\] (18)

For simplicity, the technology is assumed to be free only within one country.
\[ \frac{d\bar{\omega}}{dL} = \frac{1}{L^* S'(\bar{z}) + \frac{\beta L^*}{L^2 S(\bar{z})}} \]
\[ \frac{d\bar{z}}{dL} = \frac{1}{L^* S'(\bar{z}) + \frac{\beta L^*}{L^2 S(\bar{z})}} \]

It is seen from Expression (19) that the equilibrium wage rate may go up or down when the labor moves from the developing country to the developed country. The relative wage rate tends to increase if (a) \( \tau \) is larger; that is, the labor in the developed country can make better use of the new technology; or if (b), \( S(\bar{z}) \) is larger; that is, if the initial expenditure share spent on the goods produced in the developed country is smaller, because the immigrants can readily participate in the production of high-tech goods in which the host country has larger leading margin in productivity.

As for the equilibrium marginal good, it always declines because
Figure 8
the shifts of both schedules tend to expand the production range of
the developed country when labor moves to the developed country.

In Figure 8, it is assumed that, at the initial position (Point 1), the
expenditure share of the developed country is so small and \( c \) is large
enough to make \( d\bar{w} / dL > 0 \), then Schedule A tilts counterclockwise
and Schedule B will shift downwards as labor moves into the
developed country. The equilibrium point moves from point one to
two and so on. It is easy to show that both countries can benefit by
moving labor force from the developing country to the developed
country. For the developed country, since larger labor force will
prompt more innovative activities and more new technology will be
created; therefore, the technology will keep progressing along with the
labor movements. The developed country gains in terms of
productivity effects as well as trade effects. Since productivity
increases, the purchasing power of the wage rate of the developed
country will increase with respect to its own goods; the purchasing
power also increases with respect to the imported goods because of
the higher relative wage rate. As far as the developing country is
concerned, it still benefits from its emigration of labor force. Although
emigration of population widens the technological gap, the developing
country gains because of the favorable change in commodity terms of
trade. In fact, as long as the technology is biased to the high-index
goods, the developing country will unambiguously gain because of the
spill-over effects, as having been shown in Figure 4.

As the labor force keeps moving into the developed country, the
production range of the developed country will continue to expand. As \( S(z) \) becomes smaller, it is more likely that \( \bar{\omega} / dL \) will become zero (for instance, Point 2 in Figure 8). The equilibrium relative wage rate will start declining if another unit of labor moves into the developed country once Point 2 in Figure 8 is reached. The developed country will lose because of the trade effects due to the worsening factorial terms of trade; however, it may still gain because of the productivity effects. That is, the purchasing power of wage rate in the developed country will still be higher with respect to its own goods though the developed country loses with respect to the imported goods. The developed country will not lose as long as its real income is still increasing in terms of goods of both countries together. The developed country, however, will stop accepting more immigrants if its real income starts to decline with respect to all goods together.

Since the developing country will gain under any circumstances as long as the technology is biased to the high-index goods, the optimality will be reached at the point where any more labor moving into the developed country will make the people already in the developed country worse off. As shown above, the optimality will never be reached as long as \( \bar{\omega} / dL > 0 \). It follows that the necessary condition for the optimality is

\[
d\bar{\omega} / dL \leq 0
\]

and the sufficient condition for the optimality is
\[
\int_0^m \frac{\bar{\omega}}{p(z)} b(z) \, dz = 0 \quad (22)
\]

Expression (22) means that optimal population will be reached if the changes in real income weighted by expenditure shares with respect to changes in labor force is zero. Suppose Point 3 in Figure 8 is such a point; any point to the left of Point 3 indicates that any gains of the developing country by moving labor into the developed country must make the people already in the developed country worse off. It is concluded that the optimal labor force will not been reached unless the relative wage rate is declining or is about to decline. This implies that the population level may be too small for the developed country. Productivity effects must be taken into account in determining the optimal population for the developed country.

Concluding Remarks

Based on Samuelson-Kaizuka condition, if technology is treated as a public good, the developed country will devote a constant portion of its labor to innovative activities: the larger the population size, the more new technology is created. This has an interesting implication for labor migration: Immigrants fall short of the optimal level as long as the relative wage rate is increasing, and it may be too low even in the face of a declining relative wage rate. The people who stay in the
developing country will always gain as long as the labor keeps moving out. Essentially, this is about optimal population distribution. In this context, migration is a way of reaching a Pareto optimal distribution of population in the presence of two market imperfections: the externalities of technology and the absence of compensation.
References to Chapter Three


CHAPTER FOUR

THE OPTIMAL TECHNOLOGY ACQUISITION
AND
TECHNOLOGY-INDUCED INTERNATIONAL INDEBTEDNESS

This chapter deals with two issues: the first is to determine the optimal level of technology transfer from the standpoint of the adopting country; one key feature of this analysis is to consider the terms-of-trade effects of royalty payments. The second subject is to provide a model which may help explain why a technologically-mature country borrows from a country that is relatively backward in technology.

As the effects of royalty payments on the terms of trade resemble the "secondary burden" of transfer payments discussed by Keynes and Ohlin, a brief review of this debate is presented. Then a Ricardian model of a continuum of goods is used to determine the optimal level of technology dissemination for the recipient country. By purchasing technology, the productivity and the wage rate of the buyer country increases; however, the royalties paid for the acquired technology act like a transfer payment and may turn the terms of trade against the
recipient country. The optimal level of technology acquisition will be reached when the positive effect of increased productivity is balanced out by the negative terms-of-trade effect. In the last section of this chapter, a simple model is developed to show that a technology-superior country may find it to its interest to borrow from a less-developed country if technological improvements are expected in the future.

The "Secondary Burden" of Transfer Payments

Although the transfer problem can be dated back to the days of Ricardo, it became a polemical issue in the wake of the First World War when Germany was made to pay reparations. The central issue was over the existence of the "secondary burden".

In discussing the German reparations problem, Keynes divides the problem into two parts: the budgetary problem and the transfer problem, the former being the transaction of the actual reparations; the latter, the secondary terms of trade impacts resulting from such reparations. He argues that the transferor country will suffer a

---

1 A literature list regarding the early discussion of this issue can be found in J. S. Chipman, "The Transfer Problem Once Again," in G. Horwich and P. A. Samuelson (eds.), Trade, Stability and Macroeconomics, New York, Academic Press, 1974:19-78.

secondary burden because of the worsening terms of trade entailed by the reparations payments. Keynes argues that since Germany (the transferor) has to increase its export to make the reparations, the prices of it exports must decline to induce more demand and therefore the gold-rates of efficiency-wage must be reduced in Germany relative to elsewhere. It follows that Germany will suffer not only from the primary burden of the reparations but from the secondary burden of changing relative wage rates. Ohlin attacks Keynes on the ground that Keynes leaves out the flow of purchasing power. Ohlin argues that, since the purchasing power flows along with the reparations, the demand for German export goods will be higher in the transferee country because of the transfer payments, and the demand for German import goods will be lower in Germany; it therefore is not necessary that the terms of trade will turn against the transferor country. The viewpoint represented by Keynes is then called the "orthodox view", and that represented by Ohlin is the "modern view". The debate must be settled either by economic evidence or by theoretical conditions that determine which view will prevail under what conditions.

In constructing the theoretical foundations on which one tests the correctness for the orthodox view, Samuelson first clarifies the debate between Keynes and Ohlin by comparing the marginal propensities to consume in two countries in the absence of impediments. He develops an example in which Europe (the transferor) exports clothing and the U. S. (the transferee) exports foods and concludes:
whether the terms of trade will deteriorate in the orthodox manner or not depends upon the relative strength of the European and American marginal propensities-to-consume of food and clothing, and on no terms other then these income propensities.\textsuperscript{3,4}

Algebraically,

\[ \frac{C_E}{F_E} > \frac{C_A}{F_A} \]

then the paying country's terms of trade will deteriorate.

Where \( C_i \) and \( F_i \) represent the Country i's marginal propensities-to-consume of clothing and food. Samuelson acknowledges Pigou's presumption that, econometrically, Europeans tend to spend more on European goods than Americans do, and Americans have a greater average propensity to consume American goods then Europeans do; however, he argues that there is no theoretical necessity that this should be true, especially where trade barriers such as tariffs and transportation costs do not exist. In Samuelson's view, the only argument for the orthodox view to prevail is the existence of domestic goods.\textsuperscript{5} In this case, a fraction of the transferred purchasing power


\textsuperscript{4} Samuelson, "Transfer Problem".

\textsuperscript{5} Later Samuelson acknowledges that the example in Jones' "Revisited" is an exception to his earlier argument, see Samuelson, "On the Trail of ...
will be spent on the transferee’s domestic goods and the demand for the transferor’s exports will not increase enough to offset the decline in the demand for the transferor country; the terms of trade will therefore turn against the transferor country.

Johnson also elaborates on the significance of the marginal propensities and establishes another criterion:

The terms of trade of the transferor improve, remain unchanged, or deteriorate according to whether the sum of the two countries' marginal propensities on their own goods is less than, equal to, or greater than the unity.

Therefore, there is no presumption for the orthodox view to prevail without referring to restrictions on demand parameters.

The Optimal Level of Technology Acquisition in a Ricardian Model with Non-tradables

New technology is normally the result of innovative activities. It is assumed that the advanced country has advantages to carry out innovative activities, because of relative abundance of high-skilled

---

labor and a highly developed scientific sector. Lacking the ability to innovate, the developing country tends to acquire new technology from the advanced country. However, the innovative activities require resources and therefore are not free; it is common to charge royalties for the use of newly created technology. As argued by Connolly, since trade in technology does not involve any flow of tangible commodities and capital, the royalties paid by the developing country are in many ways like transfer payments. In the presence of the home-good sector, the country making the transfer payments will suffer from the worsening relative wage rate. Hence, there are advantages and disadvantages of the technology acquisition: the technology increases the productivity while the costs of technology acquisition turn the factorial terms of trade against the developing country. The problem boils down to this: how can the developing country determine the level of technology acquisition so as to maximize its welfare?

Suppose the adopting country is a small country in the acquisition of technology; namely, its demand for new technology will not affect the cost of technology; the royalty for new technology is determined in

9 Connolly, "Induced Technical Change".
the advanced country and is exogenous to the recipient country. New
technology is assumed to be created by private R&D companies in the
developed country; therefore, new technology will be licensed only if
royalties are paid, even though free technology transfer might benefit
the donor country. Suppose the productivity of new technology is
subject to the diminishing law of marginal productivity, there must
exist a point where the increase in the wage rate of the developing
country will be offset by the decrease in the relative wage rate
entailed by the transfer payments for the technology. However, this
point may not represent an optimal level of the technology acquisition,
because, by acquiring another unit of new technology, the real income
of the developing country may decrease with respect to its imported
goods, its real income may still increase in terms of its exports.
Therefore, the technology will be acquired up to a point where the
increase in real income in terms of the export goods is just equal to
the loss in real income in terms of its imported goods. At the optimal
level of technology transfer, the real wage of importing country should
not increase in terms its imports.

Define the acquired technology as a function of the royalty paid
for it and the royalty is assumed to be proportional to the technology
acquired:

\[ t = f(R), f' > 0, f'' = 0 \] (1)
where \( t \) represents the acquired technology, \( R \), the royalty. Expression (1) is the production function of technology for the country that adopts the technology. The production function presents the property of diminishing return to scale. The acquired technology is assumed to be a public good.\(^{10}\)

Define Schedule A as

\[
\omega = \alpha(t) + \beta(t)z \quad \alpha' < 0, \beta' < 0 \quad (2)
\]

In the following analysis, the acquired technology affects the productivity of the adopting country in an uniform fashion; namely, Schedule A shifts downward in a parallel fashion.\(^{11}\) Let \( S(z) \) represent the global income share spent on the goods produced by the developing country; Expression (3) follows when the trade is in balance without transfer payments:

\[
S(z)w_1L_1 = [k - S(z)]w_2L_2 \quad (3)
\]

---

\(^{10}\) The production structure outlined here is pretty much similar to that in Part II of this thesis except for that now it is the developing country that makes the decision as to how much resource should be devoted to new technology.

\(^{11}\) If new technology is biased to "high-tech" sector, namely \( \beta' < 0 \), then it is possible that the advanced country is hurt by the trade in technology and so the inconsistency of interests arises between the R&D companies and the advanced country as a whole.
where \( k \) is the expenditure share spent on the tradable sector in both countries; Subscript 1 and 2 represent the advanced country and the developing country. The left-hand side of Expression (3) is imports of the advanced country and the right-hand side, exports.

When the developing country makes a transfer payment to the advanced country, the balance equation becomes

\[
  w_2 R = S(z) [w_1 L + R] - [k - S(z)] w_2 (L_2 - R) \tag{4}
\]

where \( R \) is the transfer payment in units of the developing country's labor. Expression (4) indicates that the amount transferred is just equal to the difference between the advanced country's imports and exports. From Expression (4), the advanced country's relative wage rate can be expressed as follows:

\[
  \omega = \frac{1 - k}{S(z)} \frac{R}{L_1} + \frac{k - S(z)}{S(z)} \frac{L_2}{L_1} \tag{5}
\]

Totally differentiating Expression (2) and (5), the following equation system is obtained:

\[
  \begin{bmatrix}
  1 & -\beta \\
  1 & a_{22}
  \end{bmatrix}
  \begin{bmatrix}
  d\omega \\
  dZ
  \end{bmatrix}
  =
  \begin{bmatrix}
  \alpha' f' \ dR \\
  C_2
  \end{bmatrix} \tag{6}
\]
\[
\begin{align*}
\text{where } a_{22} &= \frac{(1 - k) S'}{S^2} \quad R \quad \frac{L_2}{L_1} \quad k \quad \frac{S'}{S} > 0 \\
C_2 &= \frac{1 - k}{S} \quad \frac{dR}{L_1} > 0
\end{align*}
\]

Solve for \( d\omega \) and \( dz \):

\[
\frac{d\omega}{\Delta} = \frac{1}{\Delta} \quad \left[ \alpha' f' \frac{dR}{a_{22}} + C_2 \right] < > 0 \quad (7)
\]

\[
\frac{dz}{\Delta} = \frac{1}{\Delta} \quad \left[ C_2 - \alpha' f' \frac{dR}{a_{22}} \right] > 0 \quad (8)
\]

where \( \Delta \) indicates \( a_{22} + 1 > 0 \). The production range of the developing country is unambiguously expanding ( \( dz \) is definitely positive) because the transfer payments as well as the acquired technology work together to expand its production range; however, the relative wage rate may turn in favor or against the developing country. \( C_2 \) in Expression (7) indicates the negative (transfer payment) effect which pushes the relative wage rate against the
technology-receiving country; however, $\alpha ' f ^ ' dR a_{22}$ indicates the positive (technology) effect. Whether the relative wage rate will turn in favor of the technology-receiving country depends on the relative size of these two effects.

In Figure 1, the developing country's relative wage rate reaches the maximum at Point 2. At Point 1 and Point 2, the developing country will be willing to acquire more technology, because its real income is increasing in terms of its own goods and in terms of its imported goods through the trade effect. Point 2 still may not be Pareto optimal, because, by acquiring another unit of new technology, the developing country will lose in terms of its imported goods, but it still gains in terms of its own goods; therefore, the necessary condition for Pareto optimality must be somewhere at the right to Point 2, and the following expression must hold:

$$d\overline{\omega} / dR > 0 \quad (9)$$

Pareto optimality will be reached when the gains with respect to its own goods are just offset by the loses with respect to its imported goods:

$$m \int_0^{\overline{\omega} / p(z)} b(z) \overline{\omega} / p(z) d\overline{\omega} / dR dz = 0 \quad (10)$$

where $b(z)$ is the expenditure share spent on good $z$, and $p(z)$ is the price of good $Z$. Suppose Point 3 in Figure 1 is such a point on which
Expression (10) holds, at any point to the left of Point 3, the developing country will continue buying new technology, and the advanced country is of course willing to provided new technology; however, once Point 3 is reached, there is no more gains from further technology transfer.
Technology-induced International Indebtedness in the Absence of Non-tradables

This section sets up a model in which the international indebtedness is induced by changes in technology development over time. It is also compatible with the overlapping-generation model with finite time horizon in that both sides of a trade make themselves better off by intertemporal borrowing/lending. It is shown that, the country expecting a stagnant future in technology will be willing to lend in the current period while the country expecting advance in future technology will borrow now and pay back the principal and interest in the future.

In a world of certainty, knowing that productivity will increase in the future, a country can maximize its intertemporal utility by borrowing now and paying it back with interest. Suppose there are two countries: an advanced country and a developing one, and three periods: Period 0, when both countries are static and the advanced country has technological superiority over the developing country; Period One, when the developing country makes progress and is catching up with the advanced country, so the advanced country loses some of the leading margin in the technology; Period two, when the advanced country picks up again while the developing country holds on technology gained during Period One.

The advanced country, knowing it will progress in the future, can borrow from the developing country and repay the loan with interest; the developing country is willing to lend because future compensation
is guaranteed. In order to highlight the fact that international indebtedness can occur because of technical change, all other factors that may result in international borrowing such as difference in time preference are excluded from consideration.

It is shown that the interest rate will equal the ratio between the global income of Period Two to that of Period One; this implies that the advanced country is willing and able to pay higher interest rates if it expects higher technological progress in the future.

Before the model is formulated, the crucial assumption on which the following analysis relies should be pointed out, that is the absence of the non-tradable sector. Whether the transfer payments affect the terms of trade depends, among other things, on the existence of the nontradable goods. In order to simplify the model, it is assumed that non-tradables are absent. This assumption implies that income will be determined solely by the state of technology and is independent of the level of lending/borrowing; so, income is well defined. It also implies that the relative wage rate will not be affected by the lending/borrowing, in other words, the relative price of commodities will be fixed within each period. As relative prices are fixed, all goods during each period can be treated as a single good.

The intertemporal utility function for the advanced country is

\[ V = V (C_1, C_2) = C_1^a C_2^{1-a} \]  \hspace{1cm} (11)

and that for the developing country is
\[ V^* = V^* \ (C^*_1, C^*_2) = C^*_1^{a*}C^*_2^{1-a*} \]  \hspace{1cm} (12)

where \( C_i \) represents the consumption of Period i; an asterisk indicates the developing country. Both countries will make intertemporal optimization subject to their income constraints. Let \( p \) represent the exchange rate between the first-period good and the second-period good. The advanced country will maximize Expression (11) subject to the following budget constraint:

\[ pC_1 + C_2 = pw_1 + w_2 \]  \hspace{1cm} (13)

where \( w_1 \) and \( w_2 \) represent the wage rate of Period one and Two in the advance country. Similarly, the developing country will maximize Expression (12) subject to

\[ pC^*_1 + C^*_2 = pw^*_1 + w^*_2 \]  \hspace{1cm} (14)

The demand functions follow immediately from Cobb-Douglas utility functions:

\[ C_1 = a( pw_1 + w_2)/p \]  \hspace{1cm} (15)

\[ C_2 = (1 - a) (pw_1 + w_2) \]  \hspace{1cm} (16)

\[ C^*_1 = a( pw^*_1 + w^*_2)/p \]  \hspace{1cm} (17)
\[ C^*_2 = (1 - a)(pw_1^* + w_2^*) \]  \hspace{1cm} (18)  

The intertemporal exchange rate can then be solved by the global budget constraint:

\[ C_1 + C^*_1 = w_1 + w_1^* \]  \hspace{1cm} (19)  

From Expression (15) - (19), the intertemporal exchange rate is:

\[ p = \frac{aw_2 + bw_2^*}{w_1 + w_1^* - aw_1 - bw_1^*} \]  \hspace{1cm} (20)  

Since \( p \) is positive, the developing country will enjoy higher real income even its technology is in stagnation in Period Two. And it is straightforward to show

\[ \frac{\partial p}{\partial w_2} > 0 \]  \hspace{1cm} (21)  

Expression (21) suggests that the advanced country will be willing to pay higher interest rate if more technological progress is expected. If the preference is time neutral, then the exchange rate is just equal to the ratio between the global income in Period two and that of Period One:
\[ p = \frac{w_2 + W^*}{W_1 + w^*} \]  \hspace{1cm} (22)

The borrowing can then be determined:

\[ B = C_1 - w_1 \]

\[ \frac{aw_2(w_1 + w^* - aw_1 - bw^*)}{aw_2 + bw^*_2} = (a-1)w_1 \]

\[ \hspace{1cm} (23) \]

Figure 2 shows that, when time preferences do not exist, the exchange rate is just equal to the slope of the diagonal. In Figure 2, the income of the advanced country is measured from \( A \) to the right (Period Two) and up (Period One); the income of the developing country is measured from \( B \) to the left (Period Two) and down (Period One). Since the developing country's technology is identical for Period One and Two, its income should be identical too; it appears a square with \( O \) and \( B \) being two corners. The advanced country will make progress during Period Two; so, its income will be higher during Period Two and the Edgeworth box ends up being a rectangular one.

The contract curve happens to be the diagonal of the box under the assumptions made above and the initial point (pre-trade point) is \( O \).

Expression (22) indicates that the exchange rate happens to be the slope of the diagonal with the opposite sign. Since \( w_1, w^*_1 \) and \( w^*_2 \) are fixed, the exchange rate is an increasing function of \( w_2 \).
only---the advanced country's income in Period Two. The lending/borrowing ratio can be determined by drawing a ray originating from $O$, with the slope being equal to the negative of the diagonal's slope. By changing the income streams, both countries maximize their intertemporal utilities.

Concluding Remarks

Since the acquisition of new technology is costly, and the royalties
paid for new technology may turn the terms of trade against the recipient country, the recipient country must make the decision regarding the level of technology acquisition. The optimal level of technology acquisition is reached when the positive effect of productivity is balanced by the negative effect of the trade effect. It must be noted that the new technology may be given away without charging any royalties if new technology is created by the central planner rather than private R&D companies.

Trade deficits experienced by a technology-mature country may be a complex phenomenon. This chapter provides one explanation: the advanced country can increases its intertemporal utility by borrowing from a less developed country if the rate of change of its productivity is expected to accelerate in the future.
References to Chapter Four


