FACTOR INTENSITIES, TECHNOLOGICAL PROGRESS, AND THE TERMS OF TRADE[1]

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In recent years the problems connected with the secular dollar shortage and the economic development of backward countries have aroused considerable interest in the relationship between economic growth and international trade. Theoretical analysis of the problems involved was pioneered by Professor J. R. Hicks[2] and further developed by Mr. E. J. Mishan,[3] Professor H. G. Johnson,[4] and Dr. W. M. Corden.[5]

In his contribution Professor Hicks advanced the proposition that in a two-country model with one economy growing and the other static, technological progress in the growing country would turn the terms of trade against it if the progress was concentrated mainly in the export industries or 'export-biased', and in favour of it if the progress was mainly in the import-competing industries or 'import-biased'. Professor Hicks's somewhat loosely formulated model was subjected to stricter analysis by the other authors mentioned. Mr. Mishan pointed out and analysed the importance of income effects on consumption for the direction of change in the terms of trade. Professor Johnson discussed the effects of various types of economic expansion such as population growth, capital accumulation, and technological progress on the terms of trade.

Dr. Corden clarified and refined the results of these authors by an elegant diagrammatic technique derived from Professor J. E. Meade.[6] One conclusion of his analysis is that the terms of trade must turn against the growing country in a two-country, two-commodity model if, at unchanged

[1] An earlier version of this paper was presented to a seminar in international economics at M.I.T. The authors are grateful to Professor C. P. Kindleberger and other members of the seminar for helpful criticism. Responsibility for any mistakes is borne by the authors alone. The first author is also indebted to the Ford Foundation for the award of a fellowship enabling him to study at M.I.T.

[2] J. R. Hicks, 'An Inaugural Lecture', *Oxford Economic Papers*, vol. v, No. 2, June 1953.

[3] E. J. Mishan, 'The Dollar Shortage: A Comment', ibid., vol. vii, No. 2, June 1955.

[4] H. G. Johnson, 'Economic Expansion and International Trade', *The Manchester School of Economic and Social Studies*, May 1955.

[5] W. M. Corden, 'Economic Expansion and International Trade: A Geometric Approach', *Oxford Economic Papers*, vol. viii, No. 2, Sept. 1956.

[6] J. E. Meade, *A Geometry of International Trade*, George Allen & Unwin, London, 1952.

terms of trade, the economic expansion is 'ultra export-biased', and in favour of the growing country if the expansion is 'ultra import-biased', provided that there are no inferior goods. By an 'ultra export-biased' expansion is meant one that results in an absolute decline in the domestic production of the imported commodity and by an 'ultra import-biased' expansion is meant one that results in an absolute decline in the output of the exported commodity.

This conclusion by itself is obvious since it merely states that if demand exceeds supply the relative price of the commodity must rise and vice versa. The next and more important step in the analysis is to find what types of expansion are 'ultra biased' so that the effect on the terms of trade is certain provided only that one makes the very weak assumption of no inferior goods. It is here that both Johnson and Corden employ a very useful theorem proved by Mr. T. M. Rybczynski.[1] The theorem states that under certain assumptions, an increase in the amount of one factor, with the other factor fixed, must result, at constant relative prices of the two commodities, in an absolute reduction in the output of the commodity that uses the augmented factor relatively less intensively than the other commodity in a two-factor, two-commodity economy.

Professor Johnson also discusses the effect of technological progress but makes the very restrictive assumption that factors are combined in the same proportions before and after the technological change; i.e. innovations are neither 'capital-using' nor 'labour-using' but 'neutral'.[2]

Under this assumption he states that if technological progress is confined to the production of one of the goods, then, at constant relative prices for the two goods, the absolute level of the output of the other good must decline. It is thus a further example of 'ultra-biased' expansion.

Dr. Corden asserts that by an argument similar to Mr. Rybczynski's it can be shown that if a productivity change is confined to the import-competing good in one country in a two-commodity trade model with the rest of the world static, the terms of trade must turn in the country's favour if the export good is not inferior in domestic consumption. This result follows if, and only if, the productivity change is 'ultra import-biased'. Thus Dr. Corden seems to have stated a generalization of Professor Johnson's proposition since he makes no restriction on the factor bias being neutral as Professor Johnson does.

Neither of these authors gives an explicit proof of these propositions. As our analysis will indicate, the problem of the effect of factor biased techno-

[1] T. M. Rybczynski, 'Factor Endowment and Relative Commodity Prices', *Economica* (new series), vol. xxii, No. 88, Nov. 1955.

[2] Sir Donald MacDougall has noted the importance of considering the factor bias accompanying technical progress for international trade problems. See *The World Dollar Problem*, Macmillan, London, 1957, p. 518.

logical change on the terms of trade, while similar in many ways to the question of the effect of changes in factor endowment, nevertheless presents sufficient additional difficulties to require a considerably more elaborate geometrical argument than that employed by Mr. Rybczynski. We therefore feel that even if it were true Dr. Corden's statement gives a somewhat misleading impression of simplicity to the problem so that a fuller examination would be worth while. However, the statement turns out not to be generally valid, as we shall proceed to show.

Our aim in this paper is to give a systematic analysis, by diagrammatic methods, of the effects of neutral and factor biased technological progress on the terms of trade in the framework of the familiar simplified model of only two factors, two commodities, and two countries.

The rest of the paper is divided into three parts. In Part I we analyse the shift in relative factor prices necessary to have relative product prices unchanged after technological progress has taken place in one industry and technique in the other is unchanged. In Part II we ascertain the direction of the shift in the output of the good produced with unchanged technology, at constant relative product prices, as a result of technological progress in the production of the other good. This will enable us to establish whether technological progress in one good only will always be 'ultra-biased' or not. In Part III international trade is introduced and the movement of the terms of trade as a consequence of technological progress is deduced from the preceding analysis. Our results are then related to those already in the literature.

Part I

The analytical tool of this section of the paper will be a diagram introduced by Mr. A. P. Lerner in his brilliant paper on factor price equalization in international trade.[1] In Fig. 1 an isoquant is drawn for each of two goods, which we assume to be the only goods produced in the economy. Let us call them Wheat and Textiles respectively. The axes represent Labour and Capital which are assumed to be the only two factors of production. The production functions for both Wheat and Textiles are assumed to be homogeneous of the first degree. In that case each of the isoquants will represent an infinite family, identical in shape and differing only in scale. The respective output levels for which each of the isoquants is drawn are such that they represent the equilibrium exchange ratio between the two goods prevailing in the economy.

The reader will realize that if we draw a common tangent to the two isoquants it must represent an equilibrium factor price ratio for the

[1] A. P. Lerner, 'Factor Prices and International Trade', *Economica* (new series), vol. xix, No. 73, Feb. 1952.

economy if it is assumed, as we do, that there is perfect competition with full factor mobility. In Fig. 1 the isoquants cut each other only once and so it is not possible to draw more than one such common tangent, which we have called *FG*. The Capital-Labour ratios are *OA* in Textiles and *OB* in Wheat. Since *OA* is steeper than *OB* we may call Textiles the capital-intensive, and Wheat the labour-intensive commodity. It is here that the

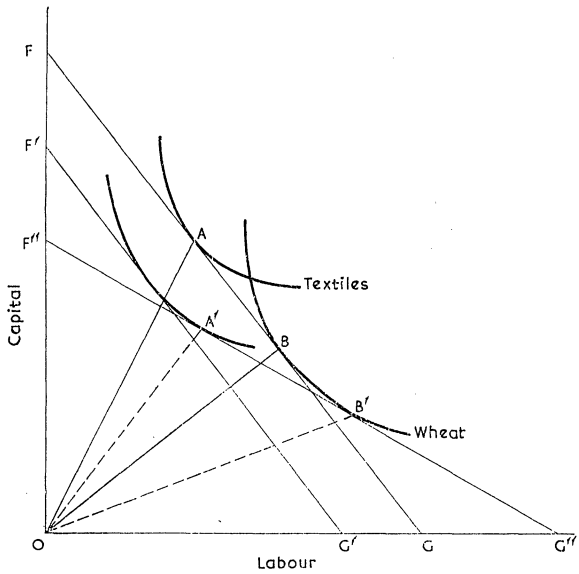

FIG. 1

importance of our assumption that the isoquants cut only once lies. If they cut twice then two common tangents could be drawn representing two possible equilibrium factor price ratios. In this case the factor intensities will reverse themselves as we move from one factor price ratio to the other. Our analysis will be confined to the original case, where the isoquants cut only once. We also rule out the case where one isoquant lies entirely within the other except at a single point.[1]

In Fig. 1 the line *FG* represents constant total cost along its entire length. The result of technological progress is to reduce the total cost of producing the same amount of a commodity. Let us suppose that there is a technological improvement in Textile production. This can be represented

[1] The concept of factor intensity has been discussed extensively in the recent literature on international trade theory. See Professor P. A. Samuelson's articles on 'International Trade and the Equalization of Factor Prices', *Economic Journal*, June 1948, and 'International Factor Price Equalization Once Again', ibid., June 1949. See also I. F. Pearce and S. F. James, 'The Factor Price Equalization Myth', *Review of Economic Studies*, 1951–2, vol. xix (2), No. 49, and R. W. Jones, 'Factor Proportions and the Heckscher-Ohlin Theorem', ibid., 1956–7, vol. xxiv, No. 63.

in Fig. 1 by the isoquant for Textiles now being tangential to a line $F'G'$, parallel to FG and indicating lower total cost at the original relative factor prices. Suppose that, as in Fig. 1, it is tangential to $F'G'$ at the point where OA cuts $F'G'$. This means that, at existing relative factor prices, the new technique has the same Capital-Labour ratio in equilibrium as the original one. Such technical progress we designate 'neutral'. The reader should note

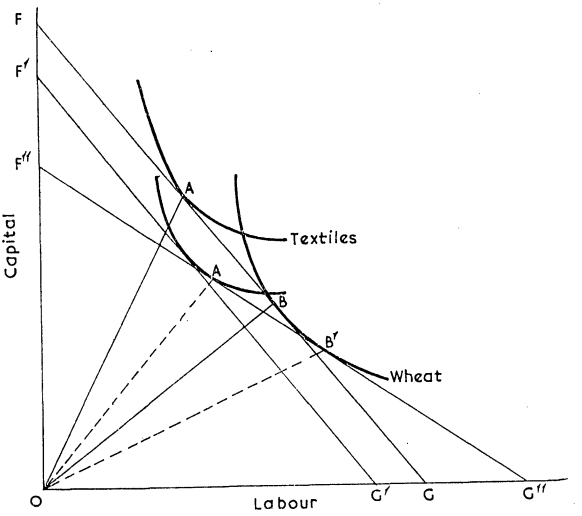

FIG. 2

that this definition of neutrality does not imply a mere renumbering of the isoquants for the commodity since the shape of the new isoquant may differ from that of the original family. For our diagram to remain independent of scale we must also assume that the new isoquants are also homogeneous of the first degree. This assumption will be made in all other cases of technological progress also.

It is clear that for the same product price ratio to prevail there must be a shift in the factor price ratio. The new factor price ratio is obtained by drawing the common tangent to the Wheat isoquant and the new Textile isoquant. As can be seen from Fig. 1 the Capital-Labour ratio must fall in both industries, to OA' in Textile and OB' in Wheat. The factor price ratio, as shown by $F''G''$, shifts in favour of Capital.

In Fig. 2 we depict the case of 'labour-using' technical progress in Textiles, since the Capital-Labour ratio in Textiles is lowered at the original relative factor prices. We have assumed that the 'labour-using' bias did not proceed sufficiently far for the new Textile isoquant and the original Wheat isoquant to intersect each other more than once. Therefore, only a single common tangent, $F''G''$, can be drawn, which indicates that the Capital-Labour ratio falls in both industries and the factor price ratio

moves in favour of Capital. Notice that at the original product price ratio the Capital-Labour ratio in Textiles falls even lower than at the same factor price ratio. The reader can show that 'capital using' technological progress in Wheat, provided that Textiles remains unambiguously the capital intensive good, will raise the Capital-Labour ratio in both industries and shift

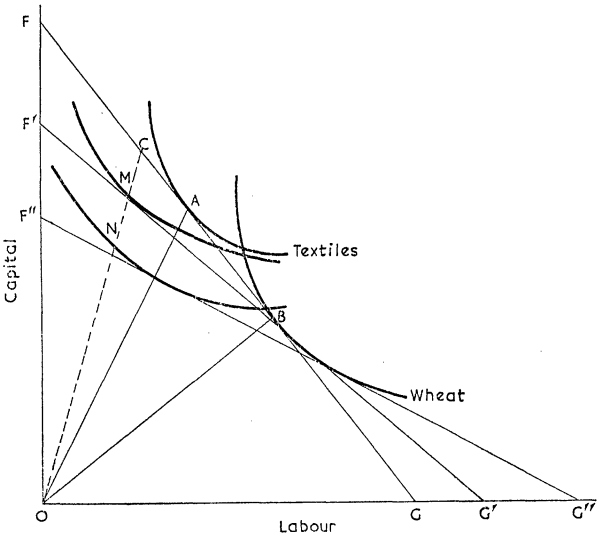

FIG. 3

the factor price ratio in favour of Labour. The Capital-Labour ratio in Wheat will be higher, at constant relative product prices, than at constant relative factor prices, after the technological change.

In Fig. 3 we consider the case of capital-using technological progress in Textiles. The dotted radial OC represents the new capital intensity of production in Textiles at FG, the original factor price ratio. The point M on OC is where a factor price line drawn parallel to FG would be tangential to the higher of the two otherwise identical new isoquants for Textiles. $F'G'$ is the common tangent to this isoquant and the Wheat isoquant. Relative factor prices have thus shifted against Labour but the Capital-Labour ratio has risen in Textiles while it falls in Wheat. Had the proportionate reduction in total costs due to technological progress been greater, however, the Capital-Labour ratio in Textiles would also fall, as can be seen by looking at the point where $F''G''$ is tangential to the isoquant which cuts O at N, which is the point at which a line parallel to FG would be tangential to it. It can be shown that labour-using technical progress in Wheat will always cause the Capital-Labour ratio in Textiles to rise, but it may rise or fall in Wheat. This completes our analysis of the shift in factor price ratios and factor proportions necessary to have relative

product prices unchanged after neutral and biased technical progress in producing either one of the goods.

Part II

In this section of the paper we shall ascertain the shift, at constant relative product prices, in the level of total output of one of the goods as a consequence of technological progress in the production of the other. We

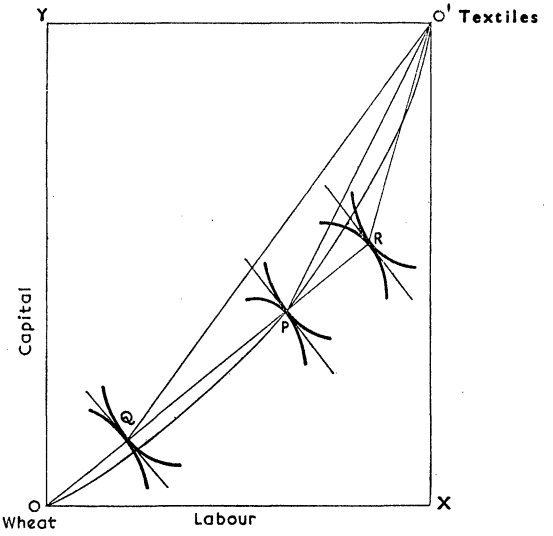

FIG. 4

assume that the supplies of Labour and Capital are fixed in amount and that each has a perfectly inelastic supply curve. As a result we can construct an Edgeworth-Bowley box diagram of production for the economy which is shown in Fig. 4.

Wheat production is measured from the lower left-hand corner of the diagram so that movement to the north-east indicates rising levels of Wheat output. The amounts of Capital and Labour used in Wheat production are measured along OY and OX respectively. Textile output is measured from the opposite corner O' and Labour used in Textile production is therefore measured along $O'Y$ and Capital along $O'X$. The solid curved line joining O and O' represents the 'efficiency-locus' which shows the maximum amount that can be produced of one good for any fixed level of the other. At any point on the efficiency-locus, such as P, a Textile isoquant is tangential to a Wheat isoquant. If a line is drawn through P, or any other point on the efficiency locus, such that it is the common tangent to both the isoquants touching at that point, its slope will indicate relative

factor prices. The way we have drawn the efficiency locus reflects our assumption that Textiles is the capital-intensive and Wheat the labour-intensive good. The point on the locus at which production actually takes places will be determined by the tastes of the society. Let us say this point is at P. The difference between P and all other points on the locus is that at this point only is the marginal rate of transformation in production equal to the marginal rate of substitution in consumption.

From Fig. 4 we see that the equilibrium Capital-Labour ratios are OP in Wheat and $O'P$ in Textiles. Suppose now that neutral technological progress takes place in Textiles. At the prevailing factor price ratio, indicated by the slope of the straight line through P, there will, by definition, be no change in the equilibrium Capital-Labour ratio in Textile production. The only change is that the point P represents a higher level of Textile output than before. The amount of Wheat produced at P is of course unchanged. Since the Wheat isoquant and the new Textile isoquant are tantential at P this point will also lie on the new efficiency-locus. The two loci will not, however, generally coincide at the other points. Only if the technological progress involves a mere renumbering of the Textile isoquants will the two loci be identically shaped.

Knowledge of the entire new efficiency locus is conveniently unnecessary for us to determine the shift in Wheat output at constant relative product prices. We know from our preceding analysis that for the product price ratio to remain constant after neutral technological improvement in Textile production the Capital-Labour ratios must fall in both industries. From Fig. 4 it is at once apparent that Wheat output must therefore contract at the same product price ratio. By identical reasoning it can be shown that neutral technological progress in Wheat will reduce the level of Textile output at constant relative product prices.

Let us now consider labour-using technological progress in Textiles. In Fig. 4 the radial $O'Q$ represents the change in the Capital-Labour ratio in Textiles at unchanged relative factor prices as a result of such a change in technique. The point Q is where the new Capital-Labour ratio line in Textiles intersects OP, the original Capital-Labour ratio line in Wheat. By the first degree homogeneity of the production functions a Wheat isoquant and a new Textile isoquant must be tangential at Q, so that Q is therefore a point on the new efficiency-locus which has the property that the factor price line passing through it has the same slope as the factor price line through P on the original efficiency-locus. It might seem surprising that relative factor prices can remain unchanged after a biased technological change in the production of one of the goods. It is easy to see, however, why this happens. The fixed factor supplies are reallocated between the two goods in such a way that the factor price ratio is left unchanged. As

can be seen from Fig. 4 this entails a reduction in the absolute amount of Wheat that is produced. From the analysis of Part I we know that for the product price ratio to remain unchanged the Capital-Labour ratio must fall in Wheat and fall even lower than $O'Q$ in Textiles. By looking at Fig. 4 we can see that this must reduce the amount of Wheat produced even lower than the output at Q. By similar reasoning the reader can show that capital-using technological progress in Wheat will cause Textile output to be reduced at constant relative product prices.

The radial $O'R$ in Fig. 4 represents the rise in the capital intensity of Textile production at the original relative factor prices as a result of capital-using technological progress in the production of that good. By the first degree homogeneity property of the production functions R indicates a point at which two isoquants are tangential and it is therefore a point on the new efficiency-locus arising from the capital-using technological change in Textiles. It shows that at constant relative factor prices the output of Wheat has increased from OP to OR. From the results of Part I we know that at the original product price ratio the Capital-Labour ratio in Wheat falls. In order to find out the direction of shift in Wheat output it is also necessary to ascertain the change in the Capital-Labour ratio in Textiles.

At this point the reader may find it convenient to refer back to Fig. 3. By looking at the lower of the two new isoquants drawn for Textiles it can be seen that the equilibrium Capital-Labour ratio in Textiles after the technical change falls below the original Capital-Labour ratio in that good. In terms of Fig. 4 this means that at a constant product price ratio the Capital-Labour ratio in Textiles must be to the left of $O'P$. The output of Wheat must therefore contract.

This, however, is by no means a necessary result. From Fig. 3 again we see that if the proportionate reduction in total cost at the original relative factor prices had been smaller, the Capital-Labour ratio in Textiles would rise above its original slope. The smaller the proportionate reduction in total cost the steeper the Capital-Labour ratio in Textiles becomes. It can never, however, exceed the slope of OC in Fig. 3 although it can approach arbitrarily close to it. It also follows from Fig. 3 that the higher the Capital-Labour ratio in Textiles after the technological change in that good, the higher will the Capital-Labour ratio in Wheat be. It is not possible, however, for it to exceed the Capital-Labour ratio at the original relative factor prices. In terms of Fig. 4 this means that at the original product price ratio it is perfectly possible for Wheat output to be very close to the level at R and therefore higher than at P. By a similar argument the reader can show that labour-using technological progress in Wheat may raise the output of Textiles at the former relative product prices.

Part III

We may now proceed directly to the analysis of the impact of technological progress on the international terms of trade. From the box diagram the production-possibilities curve of the economy can be derived. If we are provided with an indifference map revealing the tastes of the society an offer curve can be generated which will indicate the terms on which the country is prepared to trade with the rest of the world. Assuming the offer curve of the rest of the world to be given the equilibrium terms of trade and the optimum production and consumption points for the economy can be established. Let us suppose that the country finds it profitable to import the labour-intensive good, Wheat, and export the capital-intensive good, Textiles.

Then, using the Hicks–Johnson terminology explained earlier, and assuming that neither good is inferior we have obtained the following results:

1. Neutral technological progress in Wheat is 'ultra import-biased' and in Textiles it is 'ultra export-biased'. Thus the terms of trade shift in favour of the country in the first case and against it in the second.

2. Capital-using technological progress in Wheat is 'ultra import-biased' and labour-using technological progress in Textiles is 'ultra export biased'. The movement of the terms of trade will therefore be favourable to the country in the first case and unfavourable in the second.

3. Labour-using technological progress in Wheat and capital-using technological progress in Textiles have no definite effect, at constant relative product prices, on the direction of shift in the output of whichever of the two goods is produced with unchanged technique. Since such technological changes are not, in general, 'ultra biased' in their effect, the direction of shift in the terms of trade cannot be ascertained merely on the assumption that neither good is inferior. The magnitude of the positive income elasticities will be important in determining which way the terms of trade move.

We have, however, established that the greater the proportionate reduction in total costs, at the original factor price ratio, the more likely it is that either of these types of technological change will be 'ultra biased'.

We may now relate our results to the existing literature on the problem. Our first result was stated by Professor Johnson but we have provided an explicit geometrical proof. Our second result agrees with Dr. Corden's proposition that a change in productivity, if confined to the import-competing good, will turn the terms of trade in the country's favour if the exported good is not inferior. Our third result, however, disproves his proposition and the related one that technological progress confined to the exported good must move the terms of trade against the country.

Dr. Corden employs his proposition to defend Professor Hicks from a criticism made by Mr. Mishan. Professor Hicks stated that import-biased expansion in the U.S.A., in the sense of the output of the import-competing good increasing proportionately more than the output of the exported good, would turn the terms of trade in her favour. Mr. Mishan pointed out that the nature of income effects on consumption could be such as to make it quite possible for the shift to be in the opposite direction. Dr. Corden suggests that what Professor Hicks probably had in mind was the case of practically all of the increase in American productivity being concentrated on the import-competing good and therefore 'ultra import-biased', in which case only the assumption of no inferior goods would be necessary to ascertain that the shift in the terms of trade would favour the U.S. Since our analysis has shown that technical progress confined to the import-competing good is not generally 'ultra import-biased' Mr. Mishan's criticism still stands even in this case.

In our analysis we have assumed that the rest of the world remains static. The interested reader will be able to work out the consequences of the technological progress being transmitted to the rest of the world, after the first disturbance has resulted in a new equilibrium of the terms of trade. He will find that in some cases the transmission of the technological change will lead to the initial shift in the terms of trade proceeding further in the same direction and in some cases being reversed. For reasons of space we do not consider it worth while to analyse these cases in detail here.

In conclusion we may point out that our analysis may be used to discuss the problem of the effect of technological progress on the relative shares in the national income of the factors of production.[1]

[1] There is an extensive literature on this subject in classical, Marxian, and modern economics. The major modern references are J. R. Hicks, *The Theory of Wages*, Macmillan, London, 1935, and Joan Robinson, 'The Classification of Inventions', *Review of Economic Studies*, vol. v, 1937–8, reprinted in *Readings in the Theory of Income Distribution*, Blakiston, Philadelphia, 1946. Since in our model the amounts of the factors remain fixed, the effect on relative factor shares is known once the shift in the factor price ratio has been determined.