Estimating Highway Benefits in Underdeveloped Countries

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•TRANSPORTATION is frequently considered an area in which new investments can substantially increase output. Underdeveloped countries need techniques to identify which of the many investment alternatives have the highest potential benefits in relation to their cost. The problem is especially acute in the case of highways because their potential benefits are notoriously difficult to measure not only before an investment is made but also afterwards. Since highway benefits cannot be sold in the marketplace as are the products from industrial investments, it is exceedingly difficult to devise methods of estimating these benefits on a basis comparable with the benefits of other investments. The importance, furthermore, of improving techniques for estimating highway benefits goes beyond the desire of underdeveloped countries to assure an efficient use of their own limited investment capital. International lending agencies such as the International Bank for Reconstruction and Development have shown their willingness to make loans for highways provided the potential borrowers can demonstrate that worthwhile projects have been selected.

The importance of estimating benefits from alternative highway investments is not limited to underdeveloped countries. Highways in the United States are constructed with funds provided by the local, state, and federal governments. At each of these levels proposed construction and improvement projects are given a critical review by those responsible for the efficient use of the taxpayers' money. Before projects are approved, the taxpayers' representatives must be convinced that the anticipated benefits are commensurate with the costs.

A substantial literature has been developed on methods of estimating benefits of investments made in highway improvements. The key criterion generally recommended in this literature is the reduction in the cost of transportation which the proposed project would permit. Although additional criteria such as accident reduction and increased comfort and convenience are also considered, the key criterion remains cost reduction, widely defined to include time and other savings for both passengers and goods.

Underdeveloped countries are immediately concerned with increasing production. Cost reduction will be an adequate measure of the benefits of a highway project only insofar as it represents accurately the real increase in production which would result from the project. The authors believe that the fundamental criterion which should be used to determine investment priorities in transportation projects is the maximization of the difference between the contribution which projects make to national income and the cost of the projects.

This paper, which examines the relationship between cost reduction and production increases attributable to a highway, maintain the following:

1. Present methods used to calculate transport cost reductions are unsound conceptually because (a) they are based on a misunderstanding of the nature of the demand curve for transport, and (b) they do not recognize the importance of the presence of a complex index number problem.
2. Transport cost reductions are not an adequate measure of the increase in production which can occur, especially in underdeveloped countries.
3. A preferable method of estimating benefits in underdeveloped countries in instances where the highway improvement has a far-reaching impact on a specific region would be to estimate directly the likely increases in production which would occur.

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COST SAVINGS APPROACH

At first sight the cost reduction criterion appears excellent. When the price paid for transport reflects the product which the resources dedicated to transport could produce in alternative employments, a technological improvement which reduces the cost of transport releases some resources and permits an increase in production in other sectors. In a situation of full employment, with mobility of resources and competition within both the transport industry and the industries which use transport, it would seem that a reduction in transport cost reflects the resulting increase in total production. In Figure 1 the vertical axis measures the cost per ton-mile of transport over a given stretch of highway. The horizontal axis measures the traffic over the highway, also measured in ton-miles. Initially, the cost per ton-mile is OA and total traffic is OX_1. The total cost of transport is therefore $OABX_1$. A relatively small investment is made to improve the highway and the cost per ton-mile falls to OC. The total cost of providing OX_1 ton-miles is now only $OCDX_1$, so that there has been a cost saving on these OX_1 ton-miles of CABD. The resources which this cost saving represents are now freed to contribute to increased production in another sector of the economy.

The investment which reduced transport costs had a second effect, also shown in Figure 1. Because transport is now relatively less expensive at the margin than other production inputs, transportation will be substituted from some other productive factors and traffic over the highway increases from OX_1 ton-miles to OX_2 ton-miles. Some of the increased traffic may also be due to the increased production in other sectors of the economy permitted by the release of resources previously dedicated to transporting OX_1 ton-miles.

Assuming that a series of additional investments is made in the highway which successively reduces the cost per ton-mile to OE, then to OF, and finally to OG, each of these cost reductions affects not only the original traffic OX_1 but also the traffic generated by previous cost reductions. Thus the reduction in cost from OC to OE is applied to the traffic OX_2 rather than to OX_1 alone, and the total cost saving on this reduction is CDHE plus DJKH. The total cost savings on the reduction in cost from OA to OG are therefore ABLG plus the sum of all the smaller rectangles within BLM. Had the investments been extremely small at each stage, the total cost saving would have been the entire area ABMG.

Highway investments are seldom made in this fashion, however. More commonly, a single investment is made which affects significantly both the cost per ton-mile and the total traffic over the highway. The present cost of transport without the proposed investment is known, as is present traffic. An estimate is made of the effect of the investment on the unit cost and a traffic projection is made to take into account the traffic likely to be generated. Thus, only two points are known on the demand curve for transport: the points B and M (Fig. 1). Neither is the precise shape of the demand curve between these two points known with any certainty, so that usually the best that can be done is to assume that the increments in traffic between OX_1 and OX_5 are generated in proportion to the reductions in unit cost. Graphically, this assump-

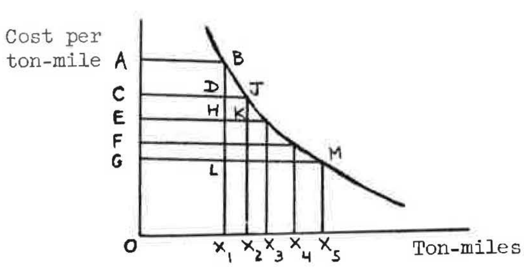


Figure 1. Transportation per ton-mile.

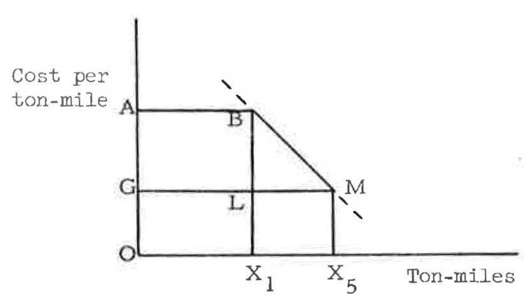


Figure 2. Effect of investment on unit cost.

tion amounts to assuming that the demand curve between points B and M is a straight line (Fig. 2).

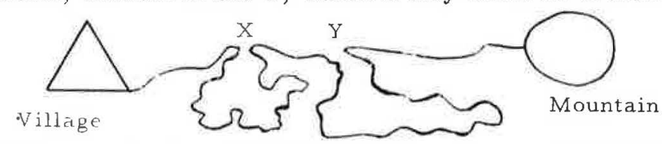
On the basis of the information in Figure 2 and the reasoning discussed, the total benefits of an investment which reduces the unit cost from OA to OG is expressed as the sum of two cost savings. On the original traffic, OX_1 ton-miles, the saving is ABLG and on the generated traffic, OX_5-OX_1 ton-miles, the saving is approximated by BLM, giving total savings or benefits of ABMG. These savings, in turn, represent resources which can now produce an equivalent value in new production elsewhere in the economy.

CRITIQUE OF COST SAVINGS METHOD

The logic of the technique presently used in estimating highway benefits appears straightforward and entirely reasonable. To evaluate its application, let us devise an imaginary arithmetical example in which an investment is made to reduce the cost of transport.

Imagine an isolated Indian village in which there are 20 workers who can devote their time to picking berries or to hunting rabbits. If a worker picks berries, which are found around the village, he can gather 12 baskets in a day. If he hunts, the same worker can capture 12 rabbits in a day. The rabbits, however, are found only on a nearby mountain, and the round-trip to and from the mountain takes three days. The total time required to obtain 12 rabbits is therefore four days, assuming that a worker can carry only 12 rabbits when he returns from the mountain.

From the following sketch it can be seen that there are two narrow points on the trail to the mountain, marked X and Y, which if they could be crossed would reduce



appreciably the time required to transport rabbits. Assume that bridges could be built across these points and that with the bridges the round-trip to and from the mountain would require only one day. Thus, with the bridges, the total time required to obtain 12 rabbits would only be two days.

With these assumptions, it is now possible to present graphically the production alternatives available to the village with and without the bridges. Without the bridges, if the village dedicates all the time of its workers to berry picking, daily production would be 240 baskets. If all the time of the workers were dedicated to obtaining rabbits, daily production would be 60 rabbits. With the bridges, the maximum possible daily production of berries does not change, as it still requires a full man-day to pick 12 baskets. The bridges, however, double the maximum number of rabbits available to the village, as now only 2 man-days are required to obtain 12 rabbits instead of 4 man-days without the bridges. Since we have assumed that there are no economies of scale either in berry picking or in obtaining rabbits, i.e., that the cost in man-days of these activities is constant whatever the amount of berries gathered or rabbits obtained, the combinations of berries and rabbits which the village can acquire are given by a straight line which connects the two maximum points. Thus, in Figure 3 line PS shows all the combinations of rabbits and berries which the village could produce without the bridges, and line PT shows the production alternatives with the bridges. An additional assumption which permits us to draw straight-

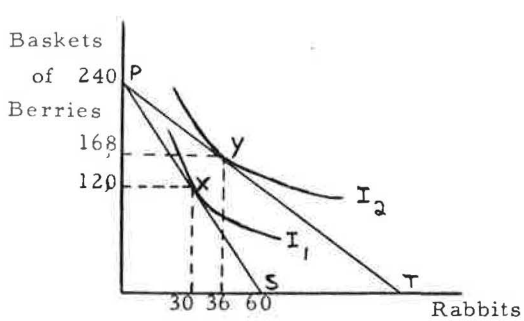


Figure 3. Village production with and without bridges.

line production possibility curves is that workers can be interchanged indiscriminately in any of the three productive processes, berry picking, rabbit hunting, and transport, with no change in productivity. In other words, the only productive input, labor, is entirely homogeneous. Finally, it is also assumed in drawing continuous curves that the labor input is finely divisible.

The actual distribution of the village's workers among the different productive processes is determined by the relative desire of the villagers for berries instead of rabbits. These relative preferences can be shown graphically through the use of indifference curves, two of which are shown in Figure 3, I_1 and I_2. The point of tangency between the production possibility curve and the highest accessible indifference curve shows how the village has decided to distribute its productive resources. Thus, without the bridges the village dedicates 10 men to picking berries, thus obtaining 120 baskets daily, and dedicates the remaining 10 men to hunting and transporting rabbits, thereby obtaining 30 rabbits. With the bridges, the production of both berries and rabbits increases, as now 14 workers gather a total of 168 baskets of berries while 6 men hunt and transport 36 rabbits. The change in total production (and consumption) of the village is summarized in Table 1.

Using this knowledge of the real increase in village production brought about by the construction of the bridges, let us see if this total benefit from an analysis of the demand curve for transport could have been predicted. Suppose that at the cost of transport without the bridges (3 man-days for each 12 rabbits), 30 rabbits are transported. Suppose also that 36 rabbits will be transported with the bridges when the cost of transport is only 1 man-day for each 12 rabbits. This information yields two points on the demand curve for transport, points B and E (Fig. 4). We do not, however, have information regarding the shape of the demand curve between these two points. Therefore, it can only be assumed that the real demand curve is best approximated by a straight line which connects B and E.

From the analysis at the beginning of this paper, it can be concluded that the benefits from the bridges are represented by the area ABEC, as this area shows the total transport cost saving brought about by the bridges. This cost saving has two components: the area ABDC represents the saving on the transport of the 30 rabbits which are produced without the bridges, and the area BED represents the saving on the generated traffic of 6 rabbits. It is clear from Figure 4 that the area ABDC is equal to 5 man-days, and that the area of BED, which is one-half of BHED, is equal to ½ man-day. The total cost saving (or resources released) is thus 5½ man-days.

Is this cost saving equal to the increase in village production given in Table 1? This question can only be answered by first specifying whether the observed increase in village production, 48 baskets of berries and 6 rabbits, is to be expressed in man-days using the production possibilities which existed before the bridges were built or those after they were built. To produce 48 baskets of berries and 6 rabbits before the bridges were built would have required 6 man-days: 4 man-days for the berries, ½ man-day to hunt the rabbits, and 1½ man-days to transport the rabbits. After the bridges were built, however, only 5 man-days are required: 4 man-days to gather the berries, ½ man-day to hunt the rabbits, and ½ man-day to transport the rabbits.

Thus it can be said that the increase in village income is equal to either 5 man-days or 6 man-days, depending on the point of reference. The cost saving derived from the demand curve for transport (Fig. 4), however, is not equal to either; there the cost saving was found to be 5½ man-days. If we wish to express the increase in village income using the production possibilities after the bridges are built, we should have considered only the rectangle ABDC, which is the quantity of rabbits transported before the bridges were built

TABLE 1

VILLAGE PRODUCTION

Bridges	Berries	Rabbits
Without	120	30
With	168	36
Increase	48	6

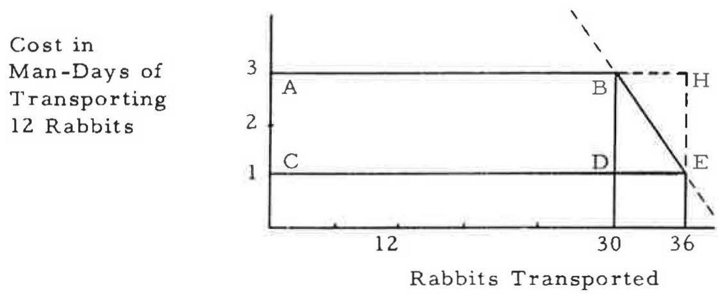


Figure 4. Rabbit production with and without bridges.

times the transport cost saving. On the other hand, if we wish to show the increase in village income in terms of resource requirements before the bridges were built, we should have multiplied the transport cost saving times the number of rabbits transported after the bridges were built, shown by the larger rectangle AHEC. The triangle BED is only some kind of fuzzy average between two clearly defined alternatives.

INDEX NUMBER PROBLEM

An index number problem familiar in economic analysis has been described. Something has been introduced in the economy which changes relative prices of different commodities and introduces ambiguity when the new situation is compared with the previous one. The way in which the problem has arisen here can be made clearer, perhaps, if we retrace some of the previous steps and introduce prices explicitly instead of measuring benefits and transport cost savings in terms of man-hours.

TABLE 2

INCREASE IN VILLAGE INCOME RELATED TO BRIDGES

Bridges	Production		Price of Rabbits in Berries	Village Income (in berries) at	
	Berries	Rabbits		Prices without Bridges	Prices with Bridges
Without	120	30	4	240	180
With	168	36	2	312	240
Increase	48	6		72	60

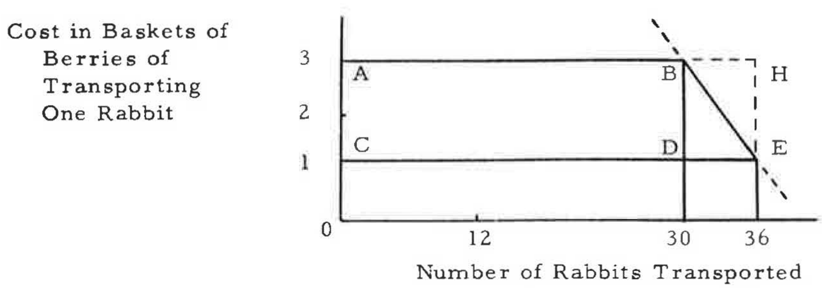


Figure 5. Number of rabbits transported vs cost of transport in terms of berries.

Referring to Figure 3, since it is assumed in this simple model that the production possibility curves are linear both with and without the bridges, so long as both products are produced the price of rabbits in terms of berries without the bridges must be 4 baskets of berries. With the bridges, the price of rabbits must be 2 baskets of berries. Regardless of the relative desire of the villagers for rabbits and berries, these prices cannot change. Thus there is no problem in pricing the increase in village production given in Table 1 using prices which exist without the bridges and prices with the bridges, as indicated in Table 2.

The data in Figure 4 can now be used to relate the number of rabbits transported to the cost of transport expressed in terms of berries (Fig. 5).

Table 2 indicates that the increase in village income expressed in prices with the bridges is equal to 60 baskets of berries. This is equal to the cost saving on the rabbits transported without the bridges, the area ABDC. Similarly, the increase in village income expressed in prices without the bridges is 72 baskets of berries, which in Figure 5 is equal to the larger rectangle AHEC. In summary, on the basis of this arithmetical example, it could be concluded that the choice of the rectangle selected as a measure of the benefits of the highway improvement depends on whether the increase in income is expressed in prices without the improvement or in prices with the improvement.

Before attempting to generalize on the basis of the example already presented, let us take a final look at the triangle BED in Figure 5, traditionally considered to be the transport cost saving on generated traffic. Because present techniques commonly consider this triangle as part of the benefits of highway investments, it is worthwhile to explore further whether the triangle has any economic significance. Although few practitioners will be willing to abandon present techniques solely on the baiss of some rabbits and berries, we shall continue to use this simplified arithmetical example since it serves to clarify the basic problem.

Two new assumptions are now added to the others previously introduced. First, instead of building the two bridges simultaneously, the villagers build first one bridge and then sometime later the second bridge. Each bridge independently reduces the round-trip time to the mountain by one day. Thus without either bridge, the maximum number of rabbits that can be obtained is 60, as was previously assumed. With only one bridge in place, the maximum number of rabbits is increased to 80, as a total of three days is required to hunt and transport 12 rabbits. With both bridges in place, the maximum number of rabbits increases to 120, as also was previously assumed.

Second, we now assume that the village always produces the maximum number of rabbits possible. Although the alternative of picking berries exists, it is not used. Thus, with no bridge the village produces 60 rabbits, with one bridge 80 rabbits, and with both bridges, 120 rabbits. These two additional assumptions are shown in Figure 6.

The demand curve for transport given these new assumptions can also be presented without difficulty (Fig. 7).

The benefits from the construction of the bridges will be expressed in terms of man-days with the alternatives available when the bridges exist. With the construction

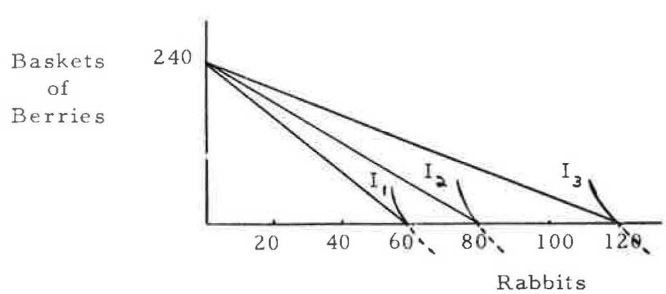


Figure 6. Number of rabbits produced vs number of bridges.

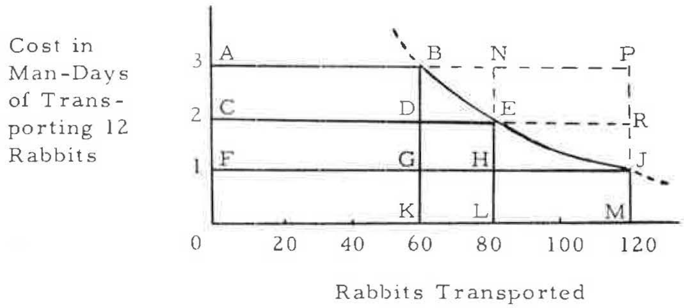


Figure 7. Demand curve for transport.

of the first bridge, the cost of transport falls from OA to OC. The benefit attributable to the bridge is shown by the area ABDC, which is equal to 5 man-days. Of these 5 man-days, the village assigns $1\frac{2}{3}$ man-days to hunting and $3\frac{1}{3}$ man-days to transporting the 20 additional rabbits at the new transport cost OC.

The construction of the second bridge lowers the cost of transport still further, from OC to OF. The benefits from the second bridge are the transport cost savings on the transport of 80 rabbits, shown by the area CEHF, which is equal to $6\frac{2}{3}$ man-days. The village assigns the released resources in accord with its preferences and the production opportunities available with the new cost of transport, OF. Thus $3\frac{1}{3}$ man-days are dedicated to hunting an additional 40 rabbits and $3\frac{1}{3}$ man-days are absorbed in the transport of the new production.

What then are the total benefits which have resulted from the construction of the two bridges measured in man-days using the production possibilities available when both bridges exist? Presumably they are the sum of the benefits from the bridges taken separately: 5 man-days from the first bridge and $6\frac{2}{3}$ man-days from the second, giving a total of $11\frac{2}{3}$ man-days. This total transport cost saving is represented by the area ABDEHF. We have explicitly excluded the triangles BDE and EHJ and have included at each step solely the transport cost saving on the transport which took place before the transport improvement.

If the situation which existed without either bridge, when 60 rabbits were produced, is compared with the situation which exists with both bridges, when 120 rabbits are produced, it is clear that the total increase in production resulting from the construction of the bridges is 60 rabbits. The man-day equivalent of these 60 rabbits when both bridges are available is only 10 man-days. Since the analysis of the transport cost savings led us to believe that the total benefits were the equivalent of $11\frac{2}{3}$ man-days, we have overestimated the benefits. Somewhere, it appears, we have counted the same benefit twice.

Figure 7 compares the original situation, when the cost of transport was OA, with the situation with both bridges, when the cost of transport is OF. From this point of view it is clear that a part of the triangle BJG, specifically the rectangle DEHG, whose area is exactly $1\frac{2}{3}$ man-days, has been included as a benefit. This area represents a benefit when the situation with one bridge is compared with the situation with two bridges, but it does not represent a benefit when the situation with no bridges is compared with that when both bridges exist, because this benefit has already been included in the area ABDC. The total cost savings resulting from the construction of the two bridges is only 10 man-days, represented by the area ABGF. Part of these savings, 5 man-days, are dedicated to transporting the additional 60 rabbits, shown by the area GJMK, and the remaining 5 man-days are now dedicated to rabbit-hunting.

Had we expressed the benefits from the two bridges in man-days based on the production possibilities which existed before either bridge was built, the benefits would be equal to 20 man-days, as only by doubling the work force could the village have doubled its production from 60 to 120 rabbits. These total benefits are represented in Figure 7 by the area APJF.

It seems clear that benefit analysis does not need to consider areas under demand curves for transport. Highway benefit analysis has been based on the theory of Marshallian partial equilibrium demand curves in instances where the theory cannot meaningfully be applied. The curve BEJ in Figure 7 is not a traditional demand curve in which one variable changes, the price of the product, whereas all other prices and income remain constant. The curve BEJ is a long-run equilibrium curve which relates the cost of transport to the demand for transport once all the variables in the economy have been adjusted to reach a new equilibrium. Specifically, the curve reflects substantial and significant changes in village income at each point. Although it is meaningful to compare two situations on the curve, such as comparing ABKO and FJMO, it is not meaningful to move along the curve and to sum up areas under it which correspond to several points, because each point corresponds to a brand new world. We can compare these two worlds, but we cannot combine them. Once we leave one point on the curve and move to another, the first point disappears.

Present techniques which include the triangle under the demand curve in estimating highway benefits represent an inappropriate and dangerous way of evading a complex index number problem. Many highway investments in underdeveloped countries affect radically the economy of the regions through which the highways pass and of the centers which the highways connect. Incomes may be increased greatly and relative price changes of different products can be large, leading to substantial shifts in the production and consumption patterns. Estimates of highway benefits based on earlier relative prices can differ widely from estimates based on prices after the investments are made. It is essential to recognize the existence of this index number problem and to confront it directly, determining the extent of the difference between the two estimates. The problem should not be hidden by using some vague average estimate which results when the triangle under the demand curve is considered as a benefit. Traditional techniques are not always applicable in underdeveloped countries; new techniques must be devised which are consistent with the nature of these economies.

A MORE GENERAL MODEL OF HIGHWAY BENEFITS

The conclusions of the previous section can be shown more clearly by using a more generalized algebraic model. The point of departure will be the two linear production possibilities curves showing the alternatives open to the village with and without the bridges used in the previous arithmetical example. The equation for the production possibilities curve without the bridges based on Figure 3 is

$$240 = A_1 + 4B_1 \tag{1}$$

where A_1 represents the baskets of berries which can be produced and B_1 is the number of rabbits which can be obtained. The construction of the bridges has the effect of increasing the number of obtainable rabbits without affecting the maximum number of berries. Thus the equation for the production possibilities curve with the bridges is

$$240 = A_2 + 2B_2 \tag{2}$$

To avoid restricting the model to the limiting assumptions and particular numbers used in the arithmetical example, it is preferable to use more generalized equations to represent the production possibilities curves with and without the bridges. Eq. 3 is the equation for the situation without the bridges and Eq. 4 corresponds to the situation with the bridges:

$$k_1 = a_1A_1 + b_1B_1 \tag{3}$$

$$k_2 = a_2A_2 + b_2B_2 \tag{4}$$

where k_1, a_1, and b_1 are constants.

Village income can also be expressed in algebraic form by introducing prices:

$$VI_1 = P_{A1}A_1 + P_{B1}B_1 \tag{5}$$

$$VI_2 = P_{A2}A_2 + P_{B2}B_2 \tag{6}$$

In Eq. 5 the village income without the bridges is expressed in terms of current prices, i.e., the prices existing without the bridges; in Eq. 6 the village income with the bridges is expressed in prices which exist with the bridges. To calculate the increase in village income which the construction of the bridges permits, however, it is necessary to use a fixed set of prices, either those which exist without the bridges or those with the bridges. The analysis will first be carried through using the prices which exist with the bridges, so Eq. 5 can be written using these prices:

$$VI^2{}_1 = P_{A2}A_1 + P_{B2}B_1 \tag{7}$$

Since this is a general equilibrium model based on only two products, the price of one of the products can be used as a numeraire and the village income can be expressed in terms of this product. This was done in the arithmetical example in Table 2 which gives both village income and the price of rabbits in terms of berries. Thus, Eqs. 6 and 7 are divided by P_{A2} (although they also could have been divided by P_{B2}):

$$\frac{VI_2}{P_{A2}} = A_2 + \frac{P_{B2}}{P_{A2}} B_2 \tag{8}$$

$$\frac{VI^2{}_1}{P_{A2}} = A_1 + \frac{P_{B2}}{P_{A2}} B_1 \tag{9}$$

Next, to show what village income was before and after the bridges were built, substitute the value of A_2 given by Eq. 4 into Eq. 8 and the value of A_1 given by Eq. 3 into Eq. 9:

$$\frac{VI_2}{P_{A2}} = \frac{k_2 - b_2B_2}{a_2} + \frac{P_{B2}}{P_{A2}} B_2 \tag{10}$$

$$\frac{VI^2{}_1}{P_{A2}} = \frac{k_1 - b_1B_1}{a_1} + \frac{P_{B2}}{P_{A2}} B_1 \tag{11}$$

To find the increase in village income, expressed in prices which exist with the bridges, Eq. 11 is subtracted from Eq. 10

$$\frac{VI_2}{P_{A2}} - \frac{VI^2{}_1}{P_{A2}} = \frac{k_2 - b_2B_2}{a_2} + \frac{P_{B2}}{P_{A2}} B_2 - \frac{k_1 - b_1B_1}{a_1} - \frac{P_{B2}}{P_{A2}} B_1 \tag{12}$$

The relative prices of the two products are determined by the negative reciprocal slope of the production possibilities curve at the particular point in question, or, more exactly:

$$-\frac{dA_2}{dB_2} = \frac{P_{B2}}{P_{A2}} \tag{13}$$

From Eq. 4, then,

$$\frac{P_{B2}}{P_{A2}} = \frac{b_2}{a_2} \tag{14}$$

Since a linear production possibilities curve is used in this model, the slope and, therefore, the ratio of prices remain constant at any point on the given curve.

When Eq. 14 is substituted into Eq. 12 and the terms are rearranged, we obtain:

$$\frac{VI_2}{P_{A2}} - \frac{VI^2_1}{P_{A2}} = \left(\frac{k_2}{a_2} - \frac{k_1}{a_1}\right) + B_1\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right) \tag{15}$$

Similarly, had the entire analysis been made using prices existing without the bridges, the increase in village income would have been

$$\frac{VI^1_2}{P_{A1}} - \frac{VI_1}{P_{A1}} = \left(\frac{k_2}{a_2} - \frac{k_1}{a_1}\right) + B_2\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right) \tag{16}$$

In the example showing the effect of the construction of bridges on the village income, $k_1 = k_2$ and $a_1 = a_2 = 1$, so that Eqs. 15 and 16 (see Fig. 4) become:

$$\frac{VI_2}{P_{A2}} - \frac{VI^2_1}{P_{A2}} = B_1 (b_1 - b_2) \tag{17}$$

$$\frac{VI^1_2}{P_{A1}} - \frac{VI_1}{P_{A1}} = B_2 (b_1 - b_2) \tag{18}$$

Since $(b_1 - b_2)$ represents the reduction of the cost of transporting rabbits and since the entire production of rabbits is transported, it was possible to determine the increase in village income solely on the basis of the total transport cost saving. But only in this simplest, and least realistic, model does it appear, from Eqs. 15 and 16, that the increase in production permitted by a highway investment can be determined solely on the basis of the transport cost saving.

A geometric demonstration may aid in the interpretation of Eqs. 15 and 16 (1). In Figures 8a and b it is assumed that without an investment in transport the production possibilities curve is represented by the line AB and that output occurs at some point N_1 representing a particular mix or composite of the two outputs OA_1 of good A and OB_1 of good B. The effect of the transport improvement is to shift the production possibilities curve to CD, and a new output level and mix is obtained at point N_2, which specifies an output of OA_2 units of A and OB_2 units of B. It is desired to calculate the increase in income which the transport improvement permits.

In Figure 8a, which corresponds to Eq. 16, the increase in income is to be measured in terms of the relative prices existing in period 1, i.e., before the transport improvement. The relative prices of the products are given by equations similar to Eqs. 13 and 14. These relative prices reflect technical coefficients of production, specifically the rate of product transformation, or the amount of one good which must be sacrificed to produce one more unit of the other good.

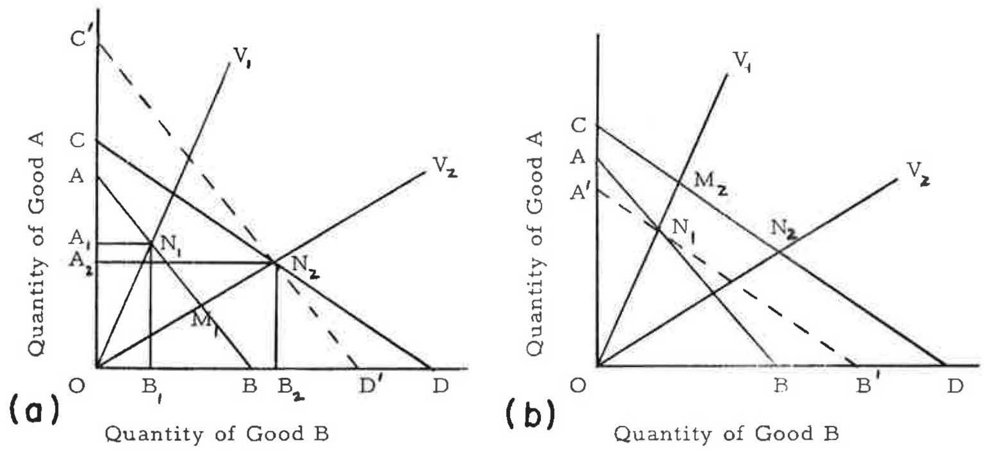


Figure 8. Production possibility curves.

Original (i.e., period 1) output valued in original prices is given by line AB, as $\frac{\Sigma p_1 q_1}{P_{A1}} = A_1 + \frac{P_{B1}}{P_{A1}} B_1$. A line C′D′ parallel to line AB is drawn through N_2, the point of production in the period 2 situation. This line represents valuation of the period 2 output in terms of period 1 relative prices, or $\frac{\Sigma p_1 q_1}{P_{A1}} = A_2 + \frac{P_{B1}}{P_{A1}} B_2$. The distance A_2C represents the valuation of period 2 output of good B at period 2 prices, while the distance A_2C' represents the valuation of that same output in period 1 prices. The difference, CC′, represents the effect of the change in the rate of product transformation brought about as a result of the transport improvement and was expressed $B_2\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right)$ in Eq. 16.

Similarly, the distance AC represents the increase in potential output of good A (which can always be transformed into good B) shown in Eq. 16 by the term $\left(\frac{k_2}{a_2} - \frac{k_1}{a_1}\right)$.

The combined expressions may be interpreted to mean that it would have been necessary to have had additional resource capacity equal to AC′ in the old situation to have been able to have produced output mix N_2 with the original technological coefficients without the bridges.

This interpretation can also be read directly from Figure 8a: the ray OV_2 represents different volumes of output of the particular product mix in the fixed proportions between goods A and B given by point ON_2. The ratio $\frac{ON_2}{OM_1}$ is an exact measure of the increase capability of the economy to produce output in those proportions. This is, of course, precisely equal to the ratio of C′D′ to AB, or $\frac{\Sigma p_1 q_2}{\Sigma p_1 q_1}$.

The converse case is shown in Figure 8b, which corresponds to Eq. 15, where constant period 2 prices are used instead of period 1 prices. A line A′ B′ parallel to line CD is drawn through the original production point N_1. The distance AA′ corresponds to the term $B_1 \left(\frac{b_1}{a_1} - \frac{b_2}{a_2} \right)$ in Eq. 15 and the distance AC to the term $\frac{k_2}{a_2} - \frac{k_1}{a_1}$. Together they represent the increase in the capability of the economy to produce in period 2 the output mix which the economy produced in period 1. This increase in productive capability is brought about by, but is not restricted to, the improvements in transport. The general measure of the capability to produce output mix N_1 is read directly from the ray OV_1 as the ratio $\frac{OM_2}{ON_1}$, which conforms to the ratio $\frac{CD}{A'B'}$.

Thus the two estimates shown in Figure 8a and b of the benefits of a highway investment which shifts the production possibility curve from AB to CD are answers to two different questions. The question asked in Figure 8a (and Eq. 16) refers to the productive capacity which the economy would have to have had before the transport investment to have produced the output mix which was produced after the investment. Figure 8b (and Eq. 15) on the other hand, refer to the increased capacity of the economy to produce after the transport investment the output mix which was produced before the investment. The decision as to which of these questions should be used to determine investment priorities in transport must be made by the planning agency of each country. The important point is that the two questions must be kept explicit so that it is always known which question has been answered. Present techniques for evaluating highway benefits that consider areas under demand curves and that frequently are not clear about which relative prices are being used do not answer either question.

EXTERNAL EFFECTS OF HIGHWAY INVESTMENTS

Even though technicians might be successful in predicting relative price changes and future traffic over a proposed transport facility, there are more fundamental objections to using transport cost savings as an estimate of the increased production which the investment would permit. The real world does not have a single homogeneous factor of production (as the workers in the Indian village) which is always fully employed. Furthermore, the transport investment may lead to changes in the production of goods which do not use the transport facility. An important effect of the transport improvement may be to result in an overall outward shift of the production possibility curve, reflected in the expression $\frac{k_2}{a_2} - \frac{k_1}{a_1}$ in Eqs. 15 and 16. This effect may well be the most important result of penetration or development roads in rural areas.

The importance of these external effects can be illustrated by returning briefly to our Indian village. Suppose that, in addition to the alternatives of berry picking and rabbit hunting, the 20 village workers could also be used to catch fish. Suppose that before the bridges are built a worker can catch four fish in a day in a stream near the village and that the fish thus need not be transported any appreciable distance. A secondary effect of constructing the bridges, however, is to raise the water level of the stream, so that when the bridges are in place, each worker can catch 12 fish in a day.

Suppose also that in addition to the 20 workers in the village there are two old men who are too arthritic to pick berries, too old to hunt rabbits, and allergic to the cold water of the fishing stream. Without the bridges they cannot aid in transport, either, because the three-day walk is too far. If the bridges are built, however, they can make a daily trip to the mountain and each can bring back 12 rabbits caught by one of the other village workers.

TABLE 3

PRODUCTION AND VILLAGE INCOME WITH AND WITHOUT BRIDGES

Bridges	Production			Prices in Berries of		Village Income at	
	Berries	Rabbits	Fish	Rabbits	Fish	Prices Without Bridges	Prices With Bridges
Without	96	30	8	4	3	240	164
With	144	36	48	2	1	432	264
Increase	48	6	40			192	100

Before the bridges are built, the 2 old men can do nothing to help, and the village assigns 8 of its workers to picking berries, 10 workers to hunting and transporting rabbits, and 2 workers to catching fish. With the bridges, however, the 2 old men can now transport rabbits, and the village assigns them plus 4 workers to hunting and transporting rabbits, 12 workers to berry picking and 4 workers to fishing. The production and village income with and without the bridges under these new assumptions are indicated in Table 3. Both income and prices are expressed in terms of baskets of berries.

Because of the significance of the relative price changes which have occurred, the increase in village income expressed in prices without the bridges is nearly twice as large as the increase measured in prices with the bridges. More importantly, it is clear that no analysis of the demand curve for transport could have led us to expect such a substantial increase in village income measured in either set of prices. Since only rabbits are transported, the demand curve for transport is the same as under the original assumptions (Fig. 5). No juggling of the demand for the transport of rabbits shown in that figure will permit us to estimate the increase in village income. When the impact of a transport investment is far-reaching, serious errors may occur if the increase in production is estimated solely on the basis of traffic over the new facility.

This conclusion is also clear when the two-commodity model developed in Eqs. 3-16 is generalized somewhat further so as to incorporate all commodities, whether or not they are transported, while still retaining the linearity of the original model. In this case the production possibility surface without the proposed transport investment is

$$k_1 = a_1A_1 + b_1B_1 + c_1C_1 + \dots + x_1X_1 \tag{19}$$

and the production possibility curve with the investment is

$$k_2 = a_2A_2 + b_2B_2 + c_2C_2 + \dots + x_2X_2 \tag{20}$$

analogous to Eqs. 3 and 4. The resulting equations for the change in real income, which are again completely analogous to Eqs. 15 and 16, are given by

$$\frac{VI_2}{P_{A2}} - \frac{{VI^2}_1}{P_{A2}} = \left(\frac{k_2}{a_2} - \frac{k_1}{a_1}\right) + B_1\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right) + C_1\left(\frac{c_1}{a_1} - \frac{c_2}{a_2}\right) + \dots + X_1\left(\frac{x_1}{a_1} - \frac{x_2}{a_2}\right) \tag{21}$$

$$\frac{{VI^1}_2}{P_{A1}} - \frac{VI_1}{P_{A1}} = \left(\frac{k_2}{a_2} - \frac{k_1}{a_1}\right) + B_2\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right) + C_2\left(\frac{c_1}{a_1} - \frac{c_2}{a_2}\right) + \dots + X_2\left(\frac{x_1}{a_1} - \frac{x_2}{a_2}\right) \tag{22}$$

The changes in the productive coefficients represented by the expressions $\left(\frac{b_1}{a_1} - \frac{b_2}{a_2}\right)$, etc., reflect more than just reductions in transport costs, since many of the goods may not be transported over the particular facility. These changes reflect economies of scale and other technological factors, some positive and others negative, which result directly or indirectly from the transport improvement. An accurate estimate of the increase in real income which occurs when a transport investment is made must take into account the changes in the production of all goods, not just those using the transport facility.

NATIONAL INCOME APPROACH TO ESTIMATING HIGHWAY BENEFITS

This paper has criticized the traditional techniques used to measure the benefits of highway investments as being inappropriate in many instances for application in underdeveloped countries. Highway investments in those economies frequently have a far-reaching impact on both incomes and relative prices in the regions where the investments are made. Dramatic changes can occur when penetration and feeder roads are constructed or when previously isolated communities are brought into the national market economy. In these circumstances the transport cost savings permitted by the highway investment, even when correctly calculated so as to take into account relative price changes, are an inadequate criterion for measuring the benefits of the investment. Investment priorities which are determined on the basis of this overly narrow criterion may well lead to carrying out projects which make a relatively small contribution to increasing real income while better projects are overlooked.

A preferable criterion would go to the heart of the problem of allocating scarce capital resources and would determine which of the proposed transport projects would make the greatest contribution to real income in relation to the cost of the projects. The application of this criterion requires an analysis of possible changes in the production of all goods and services which might result from the proposed investment. It thus goes well beyond present techniques which are concerned solely with goods which would be transported over a proposed transport facility.

The national income approach to estimating highway benefits cannot be presented here in detail (a manual for the application of the national income approach is being prepared under the Transport Research Program of the Brookings Institution), but a few of the more important aspects can be indicated. In the first place, this approach focuses on the region which the proposed transport project would serve rather than on the project alone. An economic analysis is made of the region so as to determine its productive potential, based on its natural and human resources. Present and prospective markets are studied to see if there will be a demand for the goods which the region could produce. The investment plans of both the government and private sector are examined. Using the estimates prepared by the transport experts of the possible reductions in transport costs which the proposed project would permit, agricultural, forestry, mineral, and industrial experts estimate the changes in the output of each commodity, and its market value, which could be expected to result from the proposed transport investment. All of these elements interact and each affects the others, so that frequently the analysis consists of successive approximations toward a final estimate of the increase in gross production which is likely to occur.

The national income approach takes into account explicitly the fact that all increases in the region's output will not be due solely to the investments made in transport. For production to increase, investments will also be required in other sectors, such as in irrigation, to give just one example. Planners will frequently discover that they are not evaluating an isolated transport investment but rather a package of complementary investments in several different sectors. The investment decision then becomes one of selecting the best among different investment packages so as to make the greatest contribution to real income in relation to the cost of the package.

This gross estimate of the increase in production does not yet represent an actual increase in real national income. Adjustments must be made to net out purchases of each industry from other industries to avoid double counting the same outputs, and care must be taken to net out the transfers of labor and capital from other regions of the country where they would have contributed to the national income in any case. If the new investments are likely to bring about changes in the goods produced, as will occur if the agricultural sector shifts from subsistence agriculture to production of cash crops for market, the value of production under the old system must also be subtracted.

Projections must of course be made of the traffic which is likely to use the proposed transport facility, as these will determine the technological characteristics and design of the transport project. These projections are also essential to determine that not only is the proposed project economically justified but that it also is the best way to meet the region's transport requirements.

Clearly there are many problems in using the national income approach, and frequently the estimates made will be subject to a substantial margin of error. But it is essential that the transport planner use a methodology with a sound theoretical foundation. As this paper has attempted to demonstrate, in instances where a transport investment can be expected to have a significant effect on the regional or national economy, traditional techniques of estimating benefits which examine solely transport savings are without conceptual foundation and can be seriously misleading. Whatever the difficulties of using the alternative national income approach, it is clearly preferable if highway investments are to contribute to economic development.

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