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INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT
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THE ECONOMIC BENEFITS
OF ROAD TRANSPORT PROJECTS

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PREFACE

This paper is related in nature and intent to the essay on The Evaluation of Agricultural Projects: A Study of Some Economic and Financial Aspects, issued some years ago, which was an introductory survey of conceptual and methodological problems arising in this field. It attempts to provide a brief exposition of some of these problems which arise in the economic analysis of road projects. It aims at providing a better conceptual framework by discussing some of the issues which appear most often to give rise to misunderstanding and dispute, particularly in the measurement of benefits said to result from an increase in traffic induced by a road improvement. The paper is clearly not exhaustive nor does it cover the many questions arising in filling out the framework with appropriate numbers. For more detailed discussion of those issues the reader is referred to other studies.

The authors gratefully acknowledge the stimulating comments on an earlier draft from their colleagues in the Transportation Division of the Projects Department. Discussions with Mr. Jan de Weille and Mr. Shlomo Reutlinger, of the Investment Planning Division, have been very helpful in preparing the paper. However, the customary disclaimer applies, as with all staff papers in this series: the authors alone are responsible for the views expressed.


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APPENDICES A and B
1. The economic evaluation of any project requires an assessment of the cost and benefit streams of the investment, as compared with alternatives. This involves some basic, but well-established techniques of discounting costs and benefits in future years to their "present value" in the reference year - usually that in which the capital outlay begins. These techniques, and the standard investment criteria, are here taken for granted. 1/ This paper mainly focuses on some of the conceptual and methodological problems arising in the assessment of the benefits of road projects. It only provides a framework: for more extensive treatment of some of the issues, and of the problems of filling it out with figures, the reader may consult the references given below.

2. Many of the problems in analyzing the costs and benefits of transport projects are similar to those encountered in other sectors. Nevertheless, practical difficulties differ with the sector and type of project considered. It is useful, therefore, as a preliminary to more detailed discussions of these problems, and of possible methods of solution, to broadly classify transport projects by the type of problem which they present. As with all attempts at classification, some violence will be done to reality: various types will tend to overlap in real life. Yet, a differentiation by type of project and problem is useful as some stylizing of the problem is likely to be necessary in order to make possible approximate but workable solutions. This means, of course, that in certain conditions some aspects of the problems are stressed as being of primary importance and that others are either ignored or taken as given.

1. The General Setting

Types of Road Project

3. A broad distinction may be made between transport projects involving cost comparisons and those involving comparisons of the costs and benefits. In the former, the growth of demand for transport over time is taken as given. The problem is then either to minimize total cost of transport required to meet the expected demand ("minimum cost cases"), or to compare the cost of improving roads with the resulting savings in operating costs for the given volumes of traffic ("cost saving cases"). In the other broad category of cases, the road improvement, by making reductions in transport costs possible, is considered to have a substantial stimulating effect on the growth of output and trade which will, in turn, create more traffic on the road. The benefits from the additional transport expected to develop in these cases are then the dominant factors in the

1/ This applies also to the problem of optimum timing of investments, which tends to be neglected in the usual discussion and practice of project appraisal; see on this subject, Jan de Weille, The Optimum Timing of Investments, IBRD, Economics Department (forthcoming).
economic evaluation of the investment ("development cases"). In reality, of course, the distinction gets blurred: many projects not only lower the costs of transport that would have taken place anyway, but also induce new transport. Nevertheless, for both analytical and practical purposes, it may often be justified to concentrate on one predominant aspect while ignoring others. Some brief comments follow on each of the types of cases distinguished here.

4. **Minimum Cost Cases.** One example may be the provision of transport to the coast for the output of an isolated plantation. The road to be constructed is only to serve the plantation. The demand for transport depends directly on the demand for the output of the plantation, assuming that the latter is not (within a reasonable range) significantly influenced by transport costs. The question is to determine the cheapest way of carrying given quantities of output from the plantation to the port. In such cases, given the demand forecast, it is simply a question of minimizing the present value sum of capital investment in the road, its future maintenance costs, and future operating costs of the vehicles using the road.

5. A somewhat less orthodox but not infrequent example is that of a penetration road to open up a previously isolated area for economic development. Such roads are often considered prime examples of development cases, with the primary benefits being the expected increases in net agricultural output. In many such projects, however, the road is only a part of the total investment necessary for agricultural development to take place. Other investments may involve land clearance and settlement, irrigation facilities, the provision of fertilizers, marketing and credit facilities, etc. It would appear best in most of these cases to consider the projects (or "programs") as primarily agricultural and to determine the economic merit of the road as only one item in the "package" of investments necessary to produce the expected increase in agricultural output. In such cases it is unwarranted to try to calculate a return on the road investment per se; the benefits must be related to the total "package". Analysis of such road projects is then reduced to the easier problem of working out the cheapest transport facilities required to meet the forecast demand of output from the area and its import requirements. The advantage of this approach is that it focuses attention on the crucial "complementary" investments and other factors in agriculture which ultimately determine the outcome of the project, and which tend to be lightly treated in the development road approach. It avoids the danger of exaggerated expectations of great developments - often based on historical analogies - simply from opening up the area by a new road.1/

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1/ This is not to deny, of course, that in some cases the mere provision of penetration roads have had large development effects. The explanations lie in a mixture of physical, cultural, economic, political, etc. factors and apply most to feeder roads into already settled areas; see below, para. 22 ff.
6. In the analysis of all such projects the demand for transport, in terms of volume, type, periodicity and required speed, is taken as given. The estimates of demand are derived from outside data, independent of the particular transport investment chosen. The problem is to find the most efficient solution to meeting this given transport need by minimising its costs. The benefits from transport do not enter into the problem at all. The analysis is analogous to that of power projects, where it is usually assumed that the need for power is given and is independent of its "value", and the task is to meet this given demand at the lowest possible cost.

7. Although in practice finding the minimum cost project may involve comparisons of different modes of transport, this paper is mainly concerned with road transport.1/ The task then becomes one of deciding which standard of road should be built, assuming that the types of vehicle likely to be used on the road are given. The standard of road chosen, however, involves examination of the 'trade-offs' between higher or lower initial investment with lower or higher future road maintenance costs and vehicle operating costs. The minimum cost solution is one of determining the lowest total present value of investment, road maintenance and vehicle operating costs to meet the demand required.

8. Cost Saving Cases. Here the issue is whether improvement of an already existing road is worthwhile on account of the expected savings in future vehicle operating costs and in road maintenance costs. Once again, it is assumed that the improvement would not affect the projected volume (or destination of transport). Measuring the real cost advantages may be complicated, however, by possible diversion of traffic from one mode of transport, or from one route, to another. This type of project also shows the familiar features of a choice or 'trade-off' between larger investments now in order to save on operating (or maintenance) costs later, and lower initial costs but higher costs in later years. Such problems are formally similar to those encountered when comparing hydroelectric projects with alternative developments of thermal power.

9. The basis of comparison should be the relationship of benefits to costs "with and without" the improvement not to "before and after" the improvement. The expected normal increase in traffic volume may raise unit operating costs for all vehicles above the existing level because of increasing congestion and/or the deterioration of the surface of the existing road which can only be avoided by increasing maintenance expenditures.

1/ It is appreciated that in practice comparisons of road with, say, rail costs are complicated by differences in speed, convenience, risks of losses through time, breakage or pilferage, for example. That is, a ton-km is not a homogeneous unit in the sense that a kwh is a kwh. A full analysis would involve considerations of distribution and inventory costs, of interest costs of stocks, etc.
If these greater maintenance expenditures are not made the effect may well be not only to bring forward in time the expected reconstruction date of the road but also to increase the absolute amount of physical reconstruction required, i.e., not only of the surface but also the base of the road. Vehicle operating costs on the new road, therefore, should not be compared with the existing level of operating costs but with a gradually, or possibly abruptly, worsening situation in the absence of the new facility. The frequent practice of comparing "before and after" understates the benefits.1/

10. Development Cases. In these cases the construction or improvement of the road is expected to have a significant influence on the future volume of transport. That is, by lowering transport costs between two regions a stimulating impact on trade between them is expected. Because of competition in trucking, lower costs are assumed to be passed on to the users of transport and to provide an incentive to farmers and businessmen to expand output in response to the widening of the market.

11. In these cases the volume of transport is not taken as given but is itself a function of the level of transport costs resulting from the proposed investment in a new or improved road. The estimated demand for transport is not independent of the project, as with the earlier cost comparison cases; the analysis assumes that the project itself will create transport that otherwise would not come about. The analysis of the project is therefore no longer concerned only with comparing alternative costs of meeting the requirements for a given (projected) volume of transport, but takes into account also the benefits to the economy which are reflected in the additional volume of transport taking place.

Types of Traffic Growth

12. It may be useful at this point to relate the type of transport projects distinguished above to the customary classification of types of traffic growth.2/

(a) Normal traffic growth, i.e., the increase in traffic that would take place even without improvement of the road.

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1/ Nevertheless, it is accepted that assessing costs "without" the project may involve substantial speculation while the evidence as to costs "before and after" may be obtainable from recent similar improvements in the particular country. What can be concluded, however, is that if a project is justified on a "before and after" calculation it is more than justified on a "with and without" calculation; see also para. 41, footnote 2.

2/ Terminology is not altogether standardized. Diverted and attracted traffic are used interchangeably. More important, some authors refer to traffic diverted from other modes of transportation or from other conveyances on the same route as "generated" traffic. This considers the question from the point of view of traffic on a particular road, rather than transport as a whole.
(b) Induced traffic growth, i.e., all other increases in traffic resulting from the road improvement. This may be further sub-divided, for some purposes, into:

(i) Diverted traffic, i.e., traffic diverted to the new or improved road from other road routes to the same destination; from other modes of transportation on the same route (railways, water, etc.), or from other conveyances on the same road route (passenger trips previously made by bus but now made by private car).

(ii) Generated (or development) traffic, i.e., traffic in commodities previously sold locally but now transported over the road to places where a better price can be obtained; or the traffic in commodities previously sold elsewhere after transport but now sold at better prices at different locations served by the new or improved road; or traffic resulting from an expansion of output or sales because of the lower transport costs brought about by new or improved facilities; and passenger trips now made which, because of poor and expensive transport, previously either did not take place at all or were to other destinations.

13. It should be noted that "diversion" is here defined as a shift between various possibilities of reaching the same destination. Generated traffic, however, may also involve diversion in the sense of a shift from one destination to another. In either case traffic on the old road, rail, water or air facility is reduced, and, as a result, operating costs on these may be less because of reduced congestion. Furthermore, it is clear that generated (development) traffic not only creates additional transport on the new road, but may also suppress transport that otherwise would have taken place elsewhere.

14. There is no simple relation between the different types of traffic growth and the types of project distinguished above. The differences are, of course, in the form of the analysis rather than in the projects. Minimum cost projects, such as transport for a new iron ore mine or a penetration road, typically involve development traffic since there will be no transport without the project. For analytical purposes, however, it is assumed that the projected transport volumes are given, independent of traffic costs, and attention is focused on minimizing costs of this transport; even these minimum costs may possibly be prohibitively high in that the market price of the goods (including transport costs) is too high for them to be sold competitively. Cost saving projects relate clearly to "normal traffic" and, as discussed below, rather more ambiguously to diverted traffic. In development cases the demand for transport, and the benefits
derived from it, are not taken as given but are regarded as being dependent upon the road improvement. These questions obviously arise with development traffic. This relationship occurs also with diverted traffic.

Cost and Cost Savings

15. The economic evaluation of all types of projects requires estimates of costs. The total analysis may, in some cases, consist solely of a comparison of costs, i.e., the minimum cost projects. The same is true for cost saving cases, although conventionally the savings in operating (and maintenance) costs on normal traffic resulting from the project are described as its "benefits". In such cases 'cost savings' alone play a role in the analysis; the problem of the "benefits" from transport does not arise. It is only in development and relevant mixed cases that the analysis considers both costs and benefits, in the latter sense. The remainder of this section discusses briefly the various costs involved in road transport projects. Subsequent sections deal more extensively with the evaluation of benefits from induced traffic, as described in para. 12(b) above.

16. Costs may be conveniently broken down into the following major categories:

(a) Investment costs of roads;
(b) Maintenance costs of roads;
(c) Road user costs; and
(d) Other cost factors associated with transport (e.g., accidents, produce damage or losses).

Estimating these costs meets with various difficulties, relating in part to the problem of assessing the physical inputs in different types of roads, vehicles and operating conditions, and in part to their valuation. Investment and maintenance costs are, in principle, relatively simple to estimate, although the errors, in practice, may be substantial. More comparative data

1/ In making an economic evaluation of a transport project, costs and benefits should be evaluated in terms of their true value to the economy which, for various reasons, may not be properly reflected in actual prices. This may require, for example, adjustments for exchange rate distortions, or to 'net out' for taxes on fuel, etc. On the question of use of shadow prices in transport analysis, see, e.g., Hans A. Adler, Sector and Project Planning in Transportation, World Bank Staff Occasional Papers Number Four, The Johns Hopkins Press, 1967.

2/ See, for example, Herman G. van der Tak and Jan de Weille, An Economic Reappraisal of a Road Project: The First Iranian Road Loan of 1959 (IRN-227), IBRD, EC-147, September 26, 1966.
on typical construction and maintenance costs and on construction periods, for different types of roads and conditions would seem helpful in keeping such estimating errors to a minimum.

17. Estimating road user costs in different conditions of surface, gradient, curves, speed and traffic congestion is more complex. A good deal of research effort has gone into trying to assess the effects of some of these factors on such direct vehicle operating cost items as fuel consumption, tire wear, vehicle maintenance and repairs as well as on vehicle utilization and thus on the cost of drivers and the depreciation and interest cost of vehicles. This research has yielded a mass of technical coefficients indicating differences in vehicle operating costs resulting from different kinds of road. Actual cost differences depend, of course, not only on these coefficients but also on differences in the valuation placed on, e.g., fuel, vehicle and driver's time, etc. By combining these various elements, efforts have been made to arrive at more objective measures of road user costs on different roads and of the savings that may be expected from road improvement. Such estimates of road user savings are a crucial part of the economic analysis of most road projects.1/ However, because of the difficulties of classification of roads and vehicles they are necessarily rough approximations which may not accurately describe any particular case. Practical measures of the costs of congestion and the savings resulting from its elimination in different circumstances are even less satisfactory.2/

18. In addition to road user costs in the usually accepted sense there are other costs directly associated with transport conditions. Higher speeds shorten the time spent by goods and passengers (including "self-driving passengers") in transit. There does not appear to be any agreed basis as to estimating the actual value to be put on time savings of persons travelling whilst at work, or to or from work, or for pleasure. On-the-job time savings are usually geared to the value of a passenger's time as reflected in his salary. There does not seem to be any demonstrable evidence as to whether this is an appropriate basis of valuing time savings in travel for other purposes. It implies that people are only interested in arriving somewhere, and not at all in getting there.3/ Sightseeing is one clear

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1/ See, Jan de Weille, Quantification of Road User Savings, World Bank Staff Occasional Papers Number Two, The Johns Hopkins Press, 1966, and literature cited therein. See also, e.g., Lionel Odier, The Economic Benefits of Road Construction and Improvements, Bureau Central d'Etudes pour les Equipements d'Outre-mer, Paris (no date).

2/ For a brief survey of some evidence, see, Alan A. Walters, The Economics of Road User Charges, EC-158, IBRD, January 11, 1968.

illustration to the contrary. The amount people are willing to pay for greater speed on, e.g., a toll road, may give some direct indication, if corrected for such factors as convenience and safety. A shorter transit time for goods (and more reliable delivery) tends to make possible smaller inventories and lower storage costs. Little appears to be known, however, about the quantitative importance of such savings on working capital and warehouses in various conditions.\footnote{For perishables - dairy products, fruit and vegetables - speed of delivery may substantially cut down on wastage, or expand the possible market horizon.}

19. More generally, and apart from speed effects, damage to goods during transport may differ greatly depending on the state of the roads and the nature of the goods being transported which may require different packing costs to prevent damage. This is, of course, relevant only for more fragile commodities. Accident rates and consequent personal injury and material damage also vary with road and traffic conditions.

20. These associated costs mainly concern the shippers or passengers, rather than the truckers. (Accidents affect, of course, both). In making cost comparisons they should, in principle, be taken into account as far as possible. Otherwise the cost comparisons may be distorted by differences in the "quality" of the transport services provided. Alternatively, transport of different quality may be looked upon as separate services, each with its own value to transport users.\footnote{This applies even more to differences in comfort or convenience.}

21. These different cost components are not equally important in all cases. It has been suggested,\footnote{See, E. K. Hawkins, "Investment in Roads in Underdeveloped Countries," Bulletin of Oxford University Institute of Statistics, November 1960.} for example, that in most underdeveloped countries the savings in direct vehicle operating costs predominate and time savings are less important, in contrast to the industrial countries where the cost of congestion is stressed. This view is based on the nature of the improvements being made: i.e., in the underdeveloped countries significant amounts of road investment are to improve road surfaces, leading to less vehicle wear and tear (and possibly road maintenance outlays), whereas in the developed countries investments are more likely to be for greater-capacity and higher-speeds, thus leading mainly to time savings. For most inter-city road projects in developing countries it would appear a good approach to rely for transport cost savings mainly on vehicle operating costs (and road maintenance outlays), and to take account of such elements.

\footnote{On inventories, see Meyer, Peck, Stenason and Zwick, The Economics of Competition in the Transportation Industries, Cambridge, 1959, pp. 190-192 and 348-353.}

\footnote{A reduction in associated costs may be treated either as a cost reduction for the shipper; or, if transport rates remain the same, as causing an equivalent shift upward in the demand curve for transport. See also below, para. 47 ff.}
as inventory savings, damage reduction and improvements in comfort — only when they are demonstrably significant. Further research work on the quantification of these aspects, to get a clearer idea of their relative importance in various circumstances, would seem desirable.

Benefits from Induced Traffic

22. In the previous sub-section we touched on the road user savings benefits from a road improvement, i.e., the cost savings on normal traffic. We turn now to the principal concern in this paper; the evaluation of the benefits from induced traffic. What are the benefits from an increase in transport resulting from a road improvement? A simple approach would measure the gross benefits of induced traffic by its market value to transport users, as measured by the product of the additional volume (e.g., ton km., tons, or vehicle journeys) and the corresponding unit price of the transport concerned. This would be quite justified if the increase in transport were small, or if the demand for the particular transport services were perfectly elastic. Unfortunately, in practice, these conditions are in many cases not met. Improvements, and the resulting increase in traffic, are often not small, either because of inherent indivisibilities or because discrete changes are made rather than "marginal" adjustments, and demand for transport services cannot normally be considered perfectly elastic. In that case "revenue" from induced traffic is not an adequate measure of its gross benefits; additional "surplus" should also be taken into account. Evaluation of benefits from induced traffic in terms of consumer (and producer) surplus will be discussed at some length below.

23. The next section considers the benefits from development traffic, and the underlying factors determining their importance; to illustrate the argument, it uses a simple model of transport improvement between two regions. This is followed by a section discussing the complications arising when a third region is affected. A later section considers whether the conclusions alter when transport costs are increasing for larger volumes of traffic because of congestion. The measurement of benefits on diverted traffic is dealt with next, followed by a discussion of the effects of various market imperfections on the benefits of a road improvement. A final section comments on the relation between various measurements of surplus, so-called secondary benefits, and the risk of possible double-counting of benefits.

2. A Simple Two-Regional Model

24. The factors determining the gross value of the additional transport induced by lower transportation costs may be illustrated by a simple example. Say a poor road between a "region" and the "center" is improved, and transport costs of the shipper are reduced. The volume of transport of a commodity between the center and the region depends on the price differential existing between the center and the region, and on the price elasticities of supply and demand in both the region and the center. For ease of exposition, the price differential between regions and center is assumed to consist solely of transport costs; other distribution costs and profits are ignored. With lower transport costs on the new road,
FIGURE I

Region A

Region B
transport will tend to grow until for each commodity the price differential between region and center is narrowed to the new unit transport cost to the shipper.1/ Part of the increase in the volume of transport (the "production allocation effect") may involve higher output in the region for sale in the center, stimulated by lower transport costs and higher net producers' prices. Another part (the "consumption allocation effect") may reflect greater shipments of commodities formerly produced and consumed in the region but which are now, on account of the reduction in transport costs, more profitably exported to the center. And, similarly, of course, for traffic in the opposite direction.

25. The relative quantitative importance of these two components of generated traffic depends on the price elasticities of supply and demand of the commodity concerned.2/ For traffic from the region to the center, for example, the more inelastic is demand in the region, the less important will be the consumption allocation effect; the increase in local prices in the region when supplies are diverted to the center will choke off the growth of this traffic. Similarly, inelastic supply in the region, i.e., rapidly rising costs with expanded output, will tend to limit the production allocation effect.3/ Inelastic supply and demand in the center, on the other hand, limits the scope for total development traffic generated by the project, as even a small increase in supply from the region will depress the price in the center, thus cutting off additional development traffic.4/

26. A bit of geometry will help the discussion. In Figure I, region A is the "importing" region, or the "center", and region B "exports"; without any trade or transport, the price in A is higher than in B. If transport costs (θ_{AB}) are less than the price differential without trade, trade and transport between A and B will take place.5/

1/ Or simply the new transport rates, if distance has not been shortened, and "associated costs" (of damage, etc.) have not been reduced. Cost reductions which do not benefit the shipper through lower rates or lower "associated" costs cannot, of course, develop or generate traffic directly, but may do so via an 'income effect' by which the recipient of the savings consumes more transport.

2/ This is true if the cross elasticities are small enough to be ignored.

3/ Supply elasticities, of course, are in turn related to physical and human resource availabilities, institutional factors, etc.

4/ For complications on account of a third region, see below, para. 34 ff.

5/ In the notation used in this paper, superscript 0 always refers to the initial situation. Superscript 1 refers to the new situation. Individual subscripts A, B and C relate the variables to the regions. When two subscripts occur, such as T_{AB}, θ_{AB} the variables refer to two regions simultaneously, e.g., the volume of trade, T, between A and B is T_{AB}. 
27. Suppose, for example, that with the old road the prices were \( P_A^0 \) and \( P_B^0 \), the difference between them being equal to the transport cost \( C_A^B \). Then \( S_A^0 \), \( S_B^0 \) would be the levels of production in A and B, respectively, and \( D_A^0 \), \( D_B^0 \) would be the levels of consumption in A and B, respectively. \( AB = (D_A^0 - S_A^0) = \delta_A^1 \) would be the volume of excess demand (or "imports") in A. Similarly, \( EF = (S_B^0 - D_B^0) = \delta_A^F \) would be the excess supply (and "exports") in B. AB, of course, would equal EF. With the new road, transport cost is reduced to, say, \( C_A^B \), corresponding to the new level of prices \( P_A^1 \) and \( P_B^1 \). As a result, imports of A become CD and exports from B become GH, with \( CD = GH \). The increase of consumption in A is greater than the fall in consumption in B. The increase in production in B is greater than the fall in production in A. The total increase in trade (and transport) equals \( DI + JC = HK + LG \). Clearly, the greater the elasticity of output in region B, the greater will be the production allocation effect in generating traffic; and the more elastic is demand in the region, the greater will be the consumption allocation effect.

28. One can easily show the relation between the demand and supply relationships in the two regions and the ordinary demand curve for transport. We shall assume for the time being that the road is the only link between the two regions. The transport demand curve corresponding to the conditions in Fig. I is shown in Fig. II below. \( OY \), in Fig. II, is the transport cost at which there is no transport. That is, \( OY \) is the level at which transport costs become prohibitive and no trade takes place. \( OX \), on the other hand, is the volume of trade when transport costs are zero. The volume of transport at cost \( C_A^B \) is \( T_A^B \) (AB in Fig. I). The volume increases to \( T_A^B \) (DC in Fig. I) when transport cost falls to \( C_A^B \). The slope of the demand curve for transport depends, of course, on the slopes of the demand and supply curves of the commodity in A and B. The slope is given by \( \frac{LM}{L + M} \), where L is the difference between the slopes of the demand and supply curves in A, and M is the difference between the slopes of the demand and supply curves in B. 1

---

1/ The relationship may be presented more concisely if the demand and supply curves in A are transformed into the excess demand curve showing how much demand exceeds supply for any given price; and, similarly, for the excess supply curve in B. From these curves one can read off directly how much will be transported (traded) for any particular level of transport.
29. The elasticity of demand for transport depends similarly on the difference between the elasticities of the demand and supply curves for commodity in A and in B. The differences are obtained, however, after weighting the elasticity of demand in A by \( V_A \), i.e., the proportion of A's consumption to A's imports; and the elasticity of supply in A by \( W_A \), i.e., the proportion of A's production to A's imports. Similarly, for B. Thus, let us write:

\[
\begin{align*}
1 & = V_A E(D_A) - W_A E(S_A) < 0 \\
\mu & = V_B E(D_B) - W_B E(S_B) < 0
\end{align*}
\]

where

\[
\begin{align*}
V_A &= \frac{D_A}{(D_A - S_A)} \quad W_A = \frac{S_A}{(D_A - S_A)} \\
V_B &= \frac{D_B}{(S_B - D_B)} \quad W_B = \frac{S_B}{(S_B - D_B)}
\end{align*}
\]

and \( E(D_A) \), \( E(D_B) \) are the elasticities of demand in A and B; and \( E(S_A) \), \( E(S_B) \) are the elasticities of supply in A and B. Then the elasticity of demand for transport from B to A, \( E(T_{AB}) \), is given by \( \frac{1}{\mu} \):

\[
(1) \quad E(T_{AB}) = \frac{1}{\mu} \frac{1}{\rho_A - \rho_B} < 0
\]

\( \frac{1}{\mu} \) See Appendix A, paras. 3-6, for derivation.
30. From the formula it is obvious that the elasticity of demand for transport will be greater, the greater are the elasticities of demand and supply for the commodity in both regions (in absolute values). Also, the greater is the amount of trade relative to regional production and consumption, the smaller will be the elasticity of the transport demand. These results are sensible and in line with what one would have expected. In special cases, the formula is further simplified. For example, when the elasticity of supply in region B is infinite, the formula reduces to:

\[ E(T_{AB}) = rL, \text{ where } r = \frac{\theta_{AB}}{P_{A}}. \]

Equivalent Measures of the Benefits

31. The benefits from the reduction in the transport cost may be measured in two equivalent ways. The total net gain in consumers' and producers' surpluses in A and B is given by the sum of the areas ABCD and EFGH in Fig. I: consumers gain in the "center" A, while in the exporting area B producers reap the benefits. ABCD represents the net gain in consumers' surplus in A and EFGH represents the net gain in producers' surplus in B. It can easily be shown that this total benefit ABCD + EFGH is exactly equal to RSWU in Fig. II, i.e., the increase in consumer surplus under the transport demand curve. The road user savings on the normal volume of traffic \( T_{AB}^0 \) are \( R = T_{AB}^0 \Delta \theta_{AB} \); and the development benefits are \( S = \frac{1}{2} \Delta T_{AB} \Delta \theta_{AB} \).

32. The size of the development benefits depends, of course, on the elasticity of the demand for transport. Specifically, the development benefits \( Y \) are given by:

\[ Y = \frac{1}{3} RS E(T_{AB}) > 0, \text{ where} \]

- \( R \) is the road user savings on normal traffic = \( T_{AB}^0 \Delta \theta_{AB} \);
- \( S \) is the relative reduction in unit transport costs = \( \frac{\Delta \theta_{AB}}{\theta_{AB}} \);
- and \( E(T_{AB}) \) is, as before, the elasticity of demand and is negative.

---

1/ This can easily be seen by letting \( m \) tend to infinity in equation (1).

2/ \( \text{ABCD + EFGH = ABJI + (ADI + BCJ) + KLEF + (HKE + LGF)} \)
   \( = (ABJI + KLEF) + (ADI + BCJ) + (HKE + LGF) \)
   \( = (P_{A}^0 - P_{A}^1) + (P_{B}^1 - P_{B}^0) T_{AB}^0 + \frac{T_{AB}^0 - T_{AB}}{2} \left[ \Delta P_{A} + \Delta P_{B} \right] \)
   \( = \Delta \theta_{AB}^0 + \frac{1}{2} \Delta T_{AB} \Delta \theta_{AB} \).

3/ \( Y = \text{area SW} = \frac{1}{2} \Delta \theta_{AB} \Delta T_{AB} = -\frac{1}{2} \left( \frac{\Delta \theta_{AB}^2}{\theta_{AB}^2} \right) T_{AB} E(T_{AB}) = -\frac{1}{2} R.S.E(T_{AB}). \)
It follows that:

$$\frac{Y}{R} = -\frac{1}{2} SE(T_{AB}) > 0,$$

i.e.,

the development benefits will be larger in relation to road user savings, the larger is the reduction in transport cost relative to the initial transport cost and the larger is the elasticity of demand for transport.

33. The changes in the elasticity of demand for transport and in the relative importance of development benefits are illustrated with the following sets of hypothetical data. 1/ The elasticity of demand for transport is given by equation (1) (para. 29), and the relative importance of development benefits by equation (4) (para. 32). Column (1) corresponds to the case where overall production does not change since the supply elasticities are zero. There is only a reallocation of demand. Column (2) corresponds to the case without reallocation of demand (since demand elasticities are zero), but with a reallocation of production following the change in the transport cost. The different values of the elasticity of transport demand and the importance of development benefits in columns (1) and (2) are the results of the difference in the initial prices. Columns (3) and (4) are identical except for the value of $E(D_A)$; a comparison shows that $E(T_{AB})$ is greater when $E(D_A)$ is greater. Columns (3) and (5) are identical except for the value of $E(S_A)$; a comparison of columns (3) and (5) reveals that $E(T_{AB})$ is greater when $E(S_A)$ is greater. Similarly, it can be shown that $E(T_{AB})$ is larger the larger is either $E(D_B)$ or $E(S_B)$. The ratio of development benefits to road user savings $\frac{Y}{R}$ varies, of course, with the elasticity of transport demand $E(T_{AB})$. It is also proportional to the percentage change in transport cost, which is 33% in our example. A smaller (or larger) reduction would change $\frac{Y}{R}$ accordingly.

<table>
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<th>(4)</th>
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<td>Production/imports in A</td>
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<td>←</td>
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<td>Consumption/exports in B</td>
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</tr>
<tr>
<td>New</td>
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<td>←</td>
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<td>←</td>
<td>→</td>
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<td>-0.682</td>
<td>-1.9</td>
<td>-3</td>
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<td>Ratio of development benefits to road user savings</td>
<td>$\frac{Y}{R}$</td>
<td>0.2</td>
<td>0.113</td>
<td>0.316</td>
<td>0.5</td>
</tr>
</tbody>
</table>

1/ See page 17 for this footnote.
3. **Impact on a Third Region**

34. Thus far we have considered only the effects of road improvement between two regions, without taking into account the fact that a third region may also be affected. Suppose there is a third region which competes with B in exporting the commodity concerned to the center A. Obviously, producers in C are likely to suffer a loss if the road between B and A is improved while transport costs between C and A ($q_{AC}$) remain the same: the competitive position of C has worsened.

35. This is illustrated in Fig. III. Before the road between A and B is improved, B exports GH to A, and C exports MN to A. \(GH + MN = AB\) is A's total imports. The transport cost between A and B is \(q_{AB} = P^0 - P^0\), and, between A and C is \(q_{AC} = P^0 - P^0\). The transport cost between A and C, \(q_{AC}\), is assumed to remain unchanged at \(q_{AC} = \bar{q}_{AC}\). When the road between A and B is improved, \(q_{AB}\) falls to \(q_{AB} = P^0 - P^0\). Since \(q_{AC}\) does not change, \(q_{AC} = P^0 - P^0\). As a result, \(P^0\) and \(P^0\) fall, but \(P^0\) rises. Consumers benefit in A and C and producers benefit in B. Trade and transport between A and B increases and that between A and C decreases. Total trade and transport increases from AB to CD. The changes in transport, and the benefits from lower transport costs, depend again on the demand and supply elasticities for the commodity in the three regions.

36. For transport between B and A, the demand curve can be drawn corresponding to the conditions of Fig. III above. 2/ Assuming that \(q_{AC}\) is constant, the relationship between \(T_{AB}\) and \(q_{AB}\) is shown as below in Fig. IV. The slope of this curve is \(\frac{M(L + N)}{L + M + N}\), when L, M and N are the difference between the slopes of the demand and supply curves in A, B and C respectively. 2/

---

Footnote 1/ from page 15:

We have the following restrictions on the weights:

\[
\begin{align*}
V_A - W_A &= 1 \\
W_B - V_B &= 1 \\
V_A &\geq 1 \\
W_A &\geq 0 \\
V_B &\geq 0 \\
W_B &\geq 1
\end{align*}
\]

1/ We assume that there is no road, or trade, between B and C.

2/ This demand curve is drawn on the assumption that C is an exporter to A and remains so. In order to guarantee that C is always an exporter a special assumption is required. This is elaborated upon in Appendix A, para. 8.

3/ For explanation, see Appendix A, para. 13.
37. The elasticity of demand for transport between B and A can be expressed again in terms of the differences in elasticities of supply and demand of the commodity in the three regions: 

\[
E(T_{AB}) = \Theta_{AB} \left[ \frac{\frac{T}{F_B} \frac{1}{m + \frac{T_{AC}}{F_B}}}{\frac{1}{T_{AB}} + \frac{\frac{T_{AB}}{F_B}}{m + \frac{T_{AC}}{F_C}}} \right] < 0,
\]

where \( m \) and \( n \) are defined as before, \( T \) is total imports of A, \( T_{AB} \) is exports of B and \( T_{AC} \) is exports of C; and \( n = V_{CB}(D_C) - W_{CB}(S_C) \), with \( V_C = \frac{S_C - D_C}{S_C} \) and \( W_C = \frac{S_C - D_C}{S_C} \). In this case also, the higher are the individual demand and supply elasticities, the higher is the elasticity of demand for transport. Similarly, the less is the dependence on trade in the regions, the higher will be the elasticity of demand for transport.

38. The benefits from lower transport costs can again be measured in two equivalent ways, either as the sum of the changes in producers' and consumers' surpluses, in Fig. III, or as the increase in the area under the demand curve for transport between A and B in Fig. IV. The consumers gain in A and C and lose in B, while the producers lose in A and C and gain in B. Referring to Fig. III, net gain equals \([ABCD + HIJG - MNQR]\)

\[1/ \text{For derivation, see Appendix A, para. 13.}\]
which is exactly equal to the area RSUW in Fig. IV.1. The loss in the competing region C is fully reflected in the demand curve for transport between A and B. Total benefits are, as before, the sum of road user savings (RSUV = \( T_{AB} \Delta Q_{AB} \)) and development benefits (SWW = \( \frac{1}{2} T_{AB} \Delta Q_{AB} \)). Equation (3) again yields the size of the development benefits. We can judge the relative importance of development benefits, as before, by using equation (4), viz., \( \frac{1}{2} SE(T_{AB}) \).

4. Congestion - Rising Transport Costs

39. Thus far we have assumed that both before and after the road improvement the cost of transport was constant over the range of traffic considered. In many, if not most, cases in developing countries this is probably a good approximation. A stylized picture of vehicle operating costs on a given road for different volumes of traffic shows a more or less horizontal segment up to the point where congestion begins; then a curve upward over the range where congestion increases, and finally a vertical segment when "full capacity" of the road is reached. In the more usual case, in developing countries, where road investments tend to be needed not so much because of congestion on existing roads, but rather to lower vehicle operating costs even though existing facilities have not yet reached a capacity restraint, the horizontal section of the curve is the most relevant one. Road improvement shifts this horizontal cost curve downward, with the results discussed above. We shall now briefly consider whether congestion and rising costs change the argument.

40. If vehicle operating costs on the improved road are rising with additional transport, the analysis is essentially the same as before. The net benefits from the road improvement are again measured

\[
\text{Net gain in producer surplus in B is } JIHG = \frac{1}{2} \Delta P_B \left( T^0_{AB} + T^1_{AB} \right).
\]

\[
\text{Net gain in consumer surplus in A is } ABCD = \frac{1}{2} \Delta P_A \left( T^0_{AC} + T^1_{AC} \right),
\]

or, since \( T = T_{AB} + T_{AC} \),

\[
ABCD = \frac{1}{2} \Delta P_A \left[ \left( T^0_{AB} + T^1_{AB} \right) + \left( T^0_{AC} + T^1_{AC} \right) \right].
\]

As \( \Delta P_A = \Delta P_C \) (transport costs between A and C are constant),

the net loss of producer surplus in C = \( \frac{1}{2} \Delta P_A \left( T^0_{AC} + T^1_{AC} \right) \).

Total net gain in A, B and C is therefore

\[
\frac{1}{2} \left( \Delta P_A + \Delta P_B \right) \left( T^0_{AB} + T^1_{AB} \right) = \frac{1}{2} \Delta Q_{AB} \left( T^0_{AB} + T^1_{AB} \right)
\]

which exactly equals the area RSUW, i.e., the change in the area under the demand curve for transport between A and B.

2/ Road improvement is likely to result not only in lower user costs but also in greater capacity because of higher possible speeds. This tends to extend the horizontal section of the cost curve. On the other hand, if demand for transport is very elastic, road improvement might result in congestion through induced traffic.
by the increase in the area under the demand curve for transport.\(^1\)

The only difference is that now this involves the producer surplus of the transport industry. As Fig. V shows, the area PQCA measures the net benefits from the road improvement. This area takes into account not only the road user savings and the development benefits as before, but also the change in producers' surplus accruing to the transport industry serving the route from B to A.

**Figure V**

1. In Fig. V, AFEM is now the road user savings \(T^0_{AB} \triangle \Theta^0_{AB}\).

AMC is the development benefits \(\frac{1}{2} T^0_{AB} \triangle \Theta^0_{AB}\). Both of these are smaller than what they would have been with a horizontal transport supply curve,\(^2\) because the fall in the transport cost \((\triangle \Theta^0_{AB} = AM)\) is less than the downward shift in the supply curve \((PQ = AB)\). Road user savings plus development benefits (ACEF) equal, as before, the sum of changes in producers' and consumers' surpluses on the commodity in the regions affected by the reduction in transport costs (cf. Fig. I or III above). In addition, however, to those benefits of the users of transport, there is a net increase in producers' surplus to the truckers providing transport between

---

1/ Provided that the supply curve measures the marginal cost of transport. If the supply curve reflects the average cost, as it usually does in practice, there are further complications which are discussed in para. 57 below.

2/ The effect of a rising supply curve of transport is given in Appendix A, Section III.
B and A, amounting to ECK.1/ The overall net benefits are therefore FACEK (= PAQ). It is obvious that the overall benefits are smaller than they would have been with a horizontal transport supply curve; i.e., FAC1K.2/ and the increase in producers' surplus of the truckers now absorbs part of the former road user savings and development benefits. The more inelastic is the supply of road service, the less important become development benefits and the share of total benefits accruing to users of transport, and the greater is the share absorbed by the transport industry as producers' surplus (profits).

1/ Total change in area under demand curve = FACE = FAGE + ACQ.
   Loss in producers' surplus = FAGE.
   Gain in producers' surplus = PGQ.
   Total net gain = FACE + PGQ - FAGE = PACQ.
   But PACQ = PABQ + ACB.
   And PABQ = FABK.
   So, we can write PACQ = (PGQ - FAGE) + FACE = FACE + ECK.
   Hence, ECK = (PGQ - FAGE) = net gain in producers' surplus.

2/ To be precise, horizontal over the relevant range of potential traffic generation. In the figure below, the fact that without the road improvement traffic has grown beyond the point K where costs begin to rise, and that on the improved road cost would begin to rise again if traffic increases sufficiently beyond F, does not affect our previous argument. Road user savings are measured by LECBA (or by LECQ if the cost curve is assumed to show average cost), and development benefits by EFC. It does illustrate, however, the possible error of making "before and after" comparisons (cf. para. 9 above), which would measure road user savings on normal traffic by LEC1A, ignoring the rise in (marginal) unit cost from OA to OG; and development traffic by EFC1 instead of EFC. Thus it would underestimate total benefits by the "peak" BCFC1. (Even if normal traffic were estimated at LM, and generated traffic at MF, there would still be a loss of the benefit peak BNC).
42. Alternatively, one might also think of the total benefits being composed of "road user savings" PABK and "development benefits" AC2B = ACB; but these are not the concepts we have used thus far and are not equivalent to the sum of changes in surplus on production and consumption of the commodity resulting from lower transport costs. PABK and AC2B would have represented the road user savings and development benefits, respectively, if the transport supply curve were horizontal and the transport demand curve were adjusted appropriately. The slope of the "adjusted" demand curve, through A and C2 instead of C1 depends, of course, on the slope of the transport supply curve, and is given by

\[
\frac{\Delta T_{AB}}{K} \]

1/ Given the "adjusted" demand curve for transport, measurement of benefits from a road improvement with upward sloping transport supply curve proceeds in exactly the same way as before in the uncongested case.

43. We have seen that in the case of a less than perfectly elastic supply of transport, the gains consist not only of the producers' and consumers' surpluses arising out of the changes in the pattern of production and consumption of the commodity, but also of the producers' surplus in the transport service industry. As the increase in the volume of trade and transport is less in this case, the change in the area under transport demand curve, reflecting benefits elsewhere, will also be less. In the extreme case of a perfectly inelastic supply of transport between A and B, the benefit of a reduction in transport cost will consist only of an increase in rent accruing to the transport service industry.

44. If the supply curve of transport between C and A is also positively sloped, then our assumption of a constant transport cost between C and A will no longer hold. This causes some complications, but does not call for any significant changes in our method or in our conclusions.2/ The only alteration necessary is to interpret the demand curve for transport between A and B as a locus of price-quantity equilibrium points, since the demand curve itself will now shift with changes in the transport cost between A and C.

5. The Benefits of Diverted Traffic

45. We have encountered already some types of diversion. As a result of a road improvement, one producing region gained at the expense of another in selling to a third market, and traffic on the improved road was consequently diverted from another road. We showed that the net benefits of such "diversion" are fully accounted for in the road user savings

1/ Where \( K = AB \) in Fig. V = \( (\Delta \theta_{AB} + \frac{\Delta T_{AB}}{h}) \), \( h \) being the positive slope of the supply curve. Note that \( ACB = \frac{1}{2} \Delta T_{AB} \cdot K \), and \( PABQ = T_{AB}^0 \cdot K \).

2/ For a detailed discussion of this case see Appendix A, Section IV.
plus development benefits as measured by the increase in the area under the demand curve for transport on the improved road. Similarly, part of the increase in traffic on the improved road may consist of a diversion of goods previously transported to and sold in another market. In all such cases the net benefits are measured by the area under the transport demand curve for the improved road, which in turn depends on supply and demand elasticities for the commodities concerned in the various regions and markets involved and the reduction in transport costs.1/ This diversion of traffic resulting from changes in production and consumption patterns of a commodity when a road is improved, is fully reflected in the development benefits on the new road: losses due to the possible decline of traffic elsewhere are already accounted for in the demand curve for transport on the improved road. There is no need to allow separately for losses on those other roads.

46. Does this also hold for "pure" diversion where a cost reduction results in the substitution of one route or mode of transport for another in transport from A to B, quite apart from any shifts in transport resulting from changes in output and consumption of commodities? Or should the loss of traffic, and surplus, on the railway or alternative road be treated as an offset to the gain in surplus on the improved road? This question is briefly considered in this section in terms of road/rail competition. The problem of diversion of traffic from one road to another is, of course, similar.

Road and Rail as Perfect Substitutes

47. So far we have assumed that the roads are used only for carrying a commodity from one region to another, that is, transport services are intermediate goods and not final consumer goods. If transport services are regarded in this way, then road and rail services should be treated as perfect substitutes. Both rail and road provide the same commodity, namely, transportation. Hence, the cost of transportation by road and by rail must be the same. This apparently contradicts the fact that rail rates and the cost of travelling by road usually differ. This is not a contradiction, however, since in our analysis the transport cost between regions is equated to the price differential between the two regions. Our definition of transport cost, therefore, includes not only rail rates and trucking costs, but also all the costs associated with "door-to-door" delivery, interest on goods in transit, breakage, etc. In other words, the total cost of "door-to-door" transportation via rail, if both rail and road services are used only for transporting a commodity from one region to another. If we regard road and rail services as perfect substitutes, then we can reinterpret the road transport demand curves derived earlier as the total demand for transportation. There is

1/ With the additional complication, discussed in Section 4 above, that in case of congestion transport costs depend on the volume of traffic.
FIGURE VI

Price of Transportation

VOLUME OF TRANSPORT
no separate demand curve for road (or rail). Then the diversion problem becomes simply one of determining the allocation of total supply between two competing suppliers of the same service. With upward sloping supply curves, the improvement of the road shifts the supply curve of road services to the right. The area under the demand curve will increase, and the producers' surplus of the truckers will increase; but there is an (partially) offsetting loss of producers' surplus by the railways. Total gains are now measured by the change in area between the total demand curve and the total supply curve of transport. This is shown in Fig. VI.

48. \( S_R \) and \( S_L \) are the supply curves of road and rail services, respectively, before improvement. \( S_R' \) is the supply curve of road, after improvement. \( S_L + S_R \) and \( S_L + S_R' \) are the total supply curves before and after improvement.1/ DD is the demand for transportation services. Initially, total supply and demand equal \( AE \), of which \( AD \) is supplied by road and \( AB \) by rail. After improvement, rail traffic declines to \( DF \) and road traffic rises to \( DI \). The total producer surplus before the improvement was \( AK^1E \) of which \( AH \) for rail and \( AI = HKL \) for road. After improvement total producer surplus becomes \( KKM^1L^1 \), which is larger than the old surplus \( AK^1E \). The rail surplus clearly goes down to \( DHF < AH \); but the new road producer surplus rises to \( HKL^1F \) which is greater than \( H^1LE \). The consumers' gain, of course, increases by \( ADE^1L^1 \), and the total net gain consists of the band \( KKM^1L^1E^1L^1 \). This is essentially the same result as the congestion case discussed earlier (paras. 40 ff.) except that the composite supply curve for rail plus road is somewhat more complex.

49. It should be noticed, in Fig. VI, that the loss of surplus by the railways is offset by the gain of surplus by the remaining rail customers plus half the gain of customers diverted from rail to road. The remaining surpluses are gained by the consumers and producers of the road services. In other words, if we estimate a "demand curve" for road transport alone, i.e., a locus of roadcost (price)/quantity equilibrium points given the supply curve for rail, we can measure the benefits from a road investment again as before by the change in area between the demand and supply curves for road transport. Provided that rail rates measure the marginal cost of the diverted traffic, there is then no need to allow separately for the loss of traffic by the railways.2/

---

1/ With horizontal supply curves, either rail or road would, of course, supply the total demand for transportation, if rail and road services are perfect substitutes. New cheap transport replaces the old high-cost transport completely!

2/ The exposition assumes that the supply curves are straightline, and that old and new supply curves are parallel.

3/ This is, of course, not a very realistic assumption. For complications arising if it is dropped, see section 6 below.
Imperfect Substitutes, Rail Prices Constant

50. If rail and road are not perfect substitutes they will have separate demand curves which cannot simply be added up into one demand curve for transport. The two demand curves will be mutually dependent, \(^1\) when the price of road services falls, the demand curve for rail shifts to the left. Let us assume, for the time being, that the price of rail services does not change in response to the decline in traffic. \(^2\) Thus there are no further repercussions of the reduction in road costs beyond the shift in the demand for rail. This is shown in Fig. VII below.

Figure VII

51. The demand curve for road services is drawn on the assumption that the price for rail services is \(P_R^0\). The road costs and price decline from \(P_R^0\) to \(P_R^1\) and road traffic expands from \(R_0\) to \(R_1\). The shift in the demand curve for rail (from \(D_L^0\) to \(D_L^1\)) reduces rail traffic, at the

\(^1\) If they were perfectly independent there would, of course, be no diversion problem.

\(^2\) The demand for road and rail, \(D_R\) and \(D_L\), are functions of both prices, \(P_R\) and \(P_L\). Since the price of rail services does not change when the demand curve for rail services shifts, the demand curve for road services does not shift. The price of rail services will not change if the supply curve of rail services is horizontal.
same rail rate $P_L^0$, from $L_0$ to $L_1$. The gain in utility (benefits) is shown by the gain in consumers surplus under the demand curve for road services (area $P_R^0 P_R A$). The reduction in the area under the rail demand curve is irrelevant. This is further discussed in Appendix B, Section I.

**Imperfect Substitutes, Rail Prices Change**

52. When both the price of road and of rail, $P_R$ and $P_L$, vary, then both the demand curves, $D_R$ and $D_L$, shift following a change in road transport cost. It is then no longer possible to measure consumers' surplus in the same way as in the previous paragraph. Computation of the consumers' surplus in this case is discussed in Appendix B, Section II. The method of computation is diagrammatically shown below in Fig. VIII.

**Figure VIII**

1/ The assumption that rail and road services are not perfect substitutes implies that these services are now being treated as consumer goods. Hence, the change in the area under the demand for road may be referred to as a change in consumers' surplus.


3/ There may, of course, be a gain also in producer surplus on the road, if the road supply curve is sloping upward.
53. The road demand curve $D_R$ is drawn on the assumption that rail does not exist ($X_L = 0$) \(1/\). At the road price $P_R^0$, demand for road services is then $OD = x_R^0$. The rail demand curve $D_L$ is drawn, in turn, on the assumption that $OD$ road services are supplied at price $P_R^0$; at price $P_L^0$ for rail, $OG$ of rail services is then demanded. The consumers' willingness to pay for $OD$ of road plus $OG$ of rail is given by $AOOC + HOGF$. Similarly, willingness to pay can be worked out in principle for other combinations of rail and road services and then compared to the previous one. Once we know the change in the willingness to pay we can also compute the change in consumer surplus. This is because the consumers' surplus is simply the total willingness to pay minus the cost incurred by the consumers.

6. Effects of Market Imperfections

54. The discussion so far has assumed that transport costs are the only reason for a price differential between two regions. All other distribution costs were ignored or implicitly assumed to be zero. Furthermore, transport rates charged to shippers were assumed to be based on marginal costs to the economy and to reflect the marginal value of the transport services to the economy. In that case our previous conclusions follow. However, other distribution costs are not negligible. In many cases transport rates are higher than the marginal cost to the economy because of monopolistic rate setting, cross-subsidization between different routes and products, government interventions, road user charges, etc.; and restrictions on transport, coupled with rate control, or a monopolistic distribution system, may make its marginal value exceed the rate charged. In this section we briefly consider whether such market imperfections call for any change in our previous conclusions.

55. We mentioned above that, for various reasons, transport rates might be above marginal costs, and the volume of transport therefore less than in the conditions assumed thus far. A road improvement results then in less road user savings, because of the smaller volume of normal traffic, but the induced benefits are not necessarily smaller than before. This depends on whether the lower costs are passed on in lower rates. If they are not at all, there are, of course, no induced traffic and benefits. On the other hand, lower transport costs might be a factor in breaking a transport monopoly and lead to a more than proportional lowering of transport rates. In that case the induced benefits would be larger and the road user savings smaller than in the standard cases discussed earlier.

\(^1/\) The special demand curve $D_R(X_L = 0)$ is not to be confused with the ordinary demand curve $D_R(P_L = P_L^0)$ used in Fig. VII. $D_R(X_L = 0)$ will be to the right of $D_R(P_L = P_L^0)$. 

56. This is illustrated in Fig. IX below: before the improvement, unit costs are OD but rates charged are OF, so that the volume of traffic is FG < DC. The road improvement reduces cost to OA. According to the earlier argument, road user savings would have been ABCD and the induced benefits BEC. However, if transport rates before the improvement are at the level OF, rather than OD, the road user savings are only AB\textsubscript{1}C\textsubscript{1}D. The induced benefits will depend on the extent to which rates decline as a result of the road improvement. If they do not at all, induced benefits will be zero. If the rates were to decline to level OA, the induced benefits would be B\textsubscript{1}BG, which is obviously much larger than the "normal" induced benefits BEC. Little can be said in general about the most likely outcome.

Figure IX

57. Taxes (ad valorem) on operating costs of vehicles have similar effects. In Fig. X, below, road user costs including tax are OA before and OB after improvement; the tax component is given by A\textsubscript{1}A and BB\textsubscript{1}, respectively. ABCD reflects the increase in consumers' surplus accruing to road users when the road is improved. In this case, however, a net change in tax revenue is likely. These losses (gains) of tax revenue, reflecting equivalent losses (gains) of utility elsewhere, must be deducted from (added to) the gain in consumers' surplus ABCD. The net change in tax revenue consists of two parts: loss of revenue on the normal volume of traffic, measured by ARSD \textsuperscript{1/}, and a gain of

\[ ARSD = AA\textsubscript{1} - DD\textsubscript{1} - RAD\textsubscript{1}S = AA\textsubscript{1} - DD\textsubscript{1} - BB\textsubscript{1}K\textsubscript{1}K. \]

\[ AA\textsubscript{1} - DD\textsubscript{1} > BB\textsubscript{1} - K\textsubscript{1}K, \]

since AA\textsubscript{1} > BB\textsubscript{1}. (The tax rates remain the same: \[ \frac{AA\textsubscript{1}}{AO} = \frac{BB\textsubscript{1}}{BO}, \text{ and } AO > BO. \)
revenue on the induced traffic, measured by $KK^1LC$. Total benefits thus amount to REMS, i.e., road user savings excluding the tax element for normal traffic, plus $KK^1LC$, i.e., the consumers' surplus on the induced traffic ($KC_D$) with the corresponding tax contribution ($KK^1LC$). The imposition of ad valorem taxes on the vehicle operating costs thus tends to enhance the importance of the induced benefits relative to the road user savings.

Figure X

58. In these examples transport rates are above marginal costs; the rates may also be below the marginal costs. In the earlier discussion of congestion we assumed that the supply curve was based on marginal social costs, i.e., marginal costs to the economy. Suppose now, more realistically, that the supply curve reflects average costs, i.e., the congestion costs of an additional truck to road users other than itself are not accounted for in the private road user costs. In that case the supply curve, $S^{SO}$ in Fig. XI, will be below the marginal-social-cost curve $MC^0$ on which our earlier argument was based. Consequently, the volume of normal traffic will now be larger ($OT^0 > OX^0$). Road user savings will, therefore, be larger, $S^{SO}BA^1 - S^{SO}BA$. The increase in traffic is now $Y^0X^1$ instead of $X^0X^1$. The benefits of this induced traffic are the sum of the gain $PB_1C$ on the traffic $Y^0X^1$ and the loss $CRQ$ on the excess traffic $X^1L$. The net benefits on the increase in traffic $Y^0X^1$ are, therefore, obviously smaller than that on

1/ "Road User Savings" and "Development Benefits" are here defined as in paragraph 42 above.
Total benefits are now \( S^0 S^1 B_1 A_1 + PB_1 C - CQR = S^0 S^1 CA + AA_1 F - CQR \). In other words, as compared with the earlier cases where rates equalled the marginal social costs, there is a gain of \( AA_1 F \) (because there is no longer a loss on the old excess traffic \( X^0 Y^0 \)) and a loss of \( CQR \) on the new excess traffic \( X^1 Y^1 \). As \( CQR > APA_1 \), the net effect of an average-cost supply curve is to reduce the benefits from a road improvement.

**Figure XI**

Thus far we discussed the effects on the benefits from a road investment of a divergence between transport rates and marginal costs to the economy. Similar results follow, of course, if transport rates diverge from the marginal values of transport. Scarcity of transport facilities combined with rate control results in private values exceeding rates. Or the private value of transport may be below its value to the economy because the demand of shippers is affected by a monopolistic structure of marketing, or government control of the commodity concerned. In other words, such distortions may keep the price differential between region and center, in the terminology used here, above the marginal cost of transport plus distribution. This may also happen when shippers are ignorant of the potentially existing market possibilities. In all such cases road user savings on normal traffic will be smaller than they otherwise would have been, and the development benefits may be either smaller or larger depending on the effect, if any, of the road improvement on the magnitude of the market imperfections.

To illustrate, in Fig. XII below, OP and OQ are unit costs of transport and rates charged by truckers, before and after improvement. \( D_0 D_1 \) is the demand curve for transport without restraints on transport or
monopoly features in distribution. In that case, as in our standard example in earlier sections, road user savings would be PQRS, and the development benefits SRT. However, if for whatever reason the volume of transport is restricted to OK = PS₁, road user savings are only PQR₁S₁. For a volume OK, the marginal value of transport in the economy is KG and its marginal cost is KS₁ (assuming constant costs). The size of development benefits depends on what happens to the gap GS₁ when transport costs fall to KR₁. If the road improvement only widens the gap between the cost of transport and its value to the economy from GS₁ to GR₁, and is fully absorbed in higher profits to middlemen, or government revenue, or windfalls for the lucky few who manage to get hold of transport, there will be no development benefits at all. At the other extreme, development benefits might be as much as GR₁T if the road improvement led also to a radical improvement of the market for transport or distribution. Even if the gap between marginal social costs and values were simply maintained at its existing level (i.e., GS₁ = G₁S₂) the development benefits GR₁S₂G₁ would be much larger than in our standard case (SRT). It is clear then that caution is required in using the standard measurements of the benefits from a road improvement.

Figure XII

61. This is also relevant for traffic diverted from rail, or from an alternative road. In the discussion of traffic diversion from rail to road, we assumed that the rail rates reflect marginal costs of the diverted traffic. If, for example, there is a government tax on rail services, then the contraction of the volume of rail services will lower government revenue. This loss of tax revenue may constitute a loss of utility. Provided this loss is a small fraction of the total revenue and government expenditure produces the same utility at the margin as any other expenditure, the loss of tax revenue can be regarded as a loss of utility. In that case,
we must adjust our previous net benefit calculations by allowing for this loss of tax revenue.1/

62. The same problem arises for any other divergence between rail rates and marginal costs. If rates exceed the marginal costs for the diverted rail traffic, there is a loss on rail traffic that should be deducted from the benefits on road traffic as measured by the change in area under the road demand curve. Conversely, if the marginal costs of the diverted rail traffic exceed the rates, there is an additional gain that should be taken into account. In practice both cases are likely to occur, depending on such factors as the rate structure of the railways, whether the divergence of traffic leads to closing of the line or involves small savings in operating costs, etc. In few cases would it seem safe to ignore these effects.

63. In paragraph 58 above, we discussed the measurement of benefits from an improvement of a congested road if we assume, realistically, that the supply curve for road transport is based on average social costs and ignores the congestion costs of an additional truck to other road users. In that case, marginal social costs of road transport exceed the average costs on which road users base their decisions to use the road. If a road improvement diverts traffic from congested roads, the reduction in congestion on these roads gives then rise to additional benefits measured by the area between the marginal and average social cost curves for the diverted volume of traffic. Whether this correction is important depends, of course, on the extent of congestion on roads from which traffic is diverted and on the size of the associated congestion costs.

64. The foregoing discussion has amply demonstrated that market imperfections give rise to substantial qualifications to our earlier conclusions concerning the measurement of the benefits from a road improvement. It also illustrates that generalizations are more difficult if allowance is made for these complications. Too much depends on the conditions governing any particular case. It is clear, however, that the reader should be wary of any mechanical application of the simple formulas given in sections 2, 3 and 4 of this paper.

7. Transport Surplus, Secondary Benefits and Double-Counting

65. We have discussed at some length the measurement of benefits from a road investment and their relation to changes in production and consumption of the commodity transported. We noted that the change in

1/ Similar effects may occur between different markets - the case discussed in section 3 - and give rise to offsetting losses in the third region that are not taken into account in the demand curve for transport between A and B. In other words, such losses should be specifically allowed for in measuring the net benefits of development traffic.
Transport Benefits and Income Changes

66. Consider the cost savings on normal traffic resulting from a road improvement. These may, of course, accrue, as we have seen, to the truckers, the shippers, or the producers of the transported commodity in the form of higher profits, land rents and wages, or to the consumers in the form of lower prices. Similarly, the benefits from induced traffic may be reflected in higher profits to shippers, higher land rents or other factor incomes or lower consumer prices. They are not only earned in the immediate area served by the road, but may accrue to beneficiaries elsewhere if they now find it profitable to use the better road and expand output and trade. At the same time, as discussed above, there are likely to be losses for producers in the competing area, or on competing routes or modes of transport. Our argument has been that in many conditions all the repercussions are reflected in the demand curve for transport on the improved road, and that a full measure of the benefits can be obtained by taking account only of the increases in the area below the demand curve for transport on the road concerned and the accompanying changes in producers' surplus of the transport industry, if any, earned on the road. (We also noted, it is worth repeating, that in cases with market imperfections in transportation or distribution affecting competing regions or modes of transport there may be other losses to be allowed for). What needs emphasizing here, however, is that there are many different but equivalent ways of measuring the benefits from transport; either on the level of the supply and demand for transport, or of the ultimate beneficiaries of better transport services. Those measures are alternatives, however. They should not be added together. One should not first measure the road user savings and then add the higher profits of the truckers; or measure the surplus on increased transport, and then add the value of increased agricultural output, or land rents, etc. To do so is plainly double-counting.2/

1/ Some reinterpretations of the "demand curve" were necessary; and the measure may break down if demand curves for competing modes are separate, i.e., if rail and road are "consumer goods" (cf. paras. 52, 53 above).

67. This should not be misunderstood. It is not argued, of course, that knowledge of the repercussions for the producers and consumers of transport services and commodities in the area of the improved road and elsewhere are not important. On the contrary, as we have seen, the interrelation of these demand and supply factors of competing regions and transport determines the extent of induced traffic. Development traffic, in sections 2 and 3, was derived from demand and supply in various regions for the commodity transported. The effects of a rising transport supply curve (section 4), and of diversion (section 5), were discussed in terms of interactions between commodity production and consumption and transport conditions, and between supply of transport by different modes. In some cases, the analysis of transport benefits may bear even more heavily on "interrelated packages". It might be convenient to bypass the problem of deriving a demand function for transport by focusing directly on the agricultural effects. This is the customary solution in irrigation projects when faced with similar problems concerning the evaluation of water. For transport projects, however, this approach appears to offer less promise, at least for trunk roads. Direct measurement of agricultural effects may be useful for the analysis of the benefits from feeder roads.1/

Further Repercussions

68. Whoever receives the immediate benefits resulting from the road improvement, the increases in income are passed on, directly or indirectly, in expenditure for consumption or investment, with subsequent further adjustments in output and income. Part of the income from cost savings may be invested, for example, in additional transport; other parts are spent on expansion of agriculture, or industry, etc., or on higher consumption, leading to further repercussions and adjustments. These effects on output and income are not necessarily in the region served by the road, but may be felt elsewhere in the economy. Again as a result, some people gain and others lose. Many different repercussion patterns are possible - depending also on the distribution of the original cost savings, or benefits from induced transport, between truckers, shippers, etc. - with many different effects on output and income distribution. All of them, however, reflect various uses made of the direct benefits (or adjustments to losses). Counting again as benefits these secondary increases in value of output and/or transport resulting from the primary benefits amounts to double-counting.

1/ For penetration roads, it was suggested above (para. 5), the major problem is probably the agricultural development scheme; the road aspects are then better treated as a minimum cost problem, thus avoiding the measurement of transport development benefits.
69. These repercussions on income and output, beyond the direct benefits from road user savings and induced transport, are not relevant for benefit-cost analysis aiming at optimization of resource allocation. A (pure) cost-saving road project, for example, without economic justification in terms of direct savings benefits cannot be made "economic" by including such indirect effects. Including profitable and unprofitable elements into one investment package with a satisfactory economic return does not make the unprofitable components economically justified. As a practical consideration, moreover, it is not clear whether, and at what point, further "tertiary" effects should be cut off. The repercussions of the project do not peter out; they do not constitute a multiplier process with leakages putting a definite limit to the magnitude of total repercussions. The problem here concerns alternative resource allocation patterns, not an increase in aggregate demand. If the latter were the problem, pumping in more purchasing power by budgetary or monetary means would be the simple answer. To take account of all repercussions and interrelationships would require detailed comparison of complete alternative investment programs and patterns of development. This is hardly a practicable task, and defeats the very purpose of project analysis, i.e., decentralized decision-making.1/

8. Conclusion

70. The conclusion of sections 2 and 3 of this paper is that all benefits from a road investment are accurately measured by the change in the area under the demand curve for transport between the regions connected by the road. This conclusion depended on the assumptions that the transport services are only valued as intermediate goods and that there is no change in the surplus of the producers of the road services as a result of the road improvement. The extension of the measure necessary when there is a change in the surplus of the truckers, because of an upward-sloping supply curve of transport on the new road, has been discussed in section 4. An upward-sloping supply curve of transport for the competing region, however, requires only some reinterpretation of the demand curve. Competing modes of transport on the same route cause further complications (section 5). If we may assume that both modes of transport supply perfectly substitutable transport services which are only used to transport commodities from one region to another, a suitable reinterpretation of the "demand curve" for road transport, maintains the previous measure of the benefits. When road services and the services of a competing mode of transport such as rail are not perfect substitutes, but are final consumer goods with separate demand curves, the net change in the consumer surplus is measured by the demand curve for road transport, provided the price of

1/ In principle, the secondary effects are reflected in the (shadow) prices of inputs and outputs of the transport service, and in the projections of demand for transport.
the competing service does not change in response to changes in the road transport costs. If it does change, however, the normal computation of the change in the consumer surplus does break down. And, as discussed in section 6, market imperfections necessitate important qualifications in the earlier measure used; in particular, they may require explicitly taking account of repercussions of road investments on the surpluses from competing routes or modes.

71. We have looked at the increase in the area between the demand and supply curves for transport as a sum of two parts: the road user savings plus induced benefits. Road user savings accrue to the initial volume of traffic, i.e., only those who use the road at the initial transport cost will realize the cost savings due to the fall in the transport cost. Hence, to calculate the road user savings we need to know the volume of traffic without improvement and the change in the transport cost brought about by the road improvement. However, in order to calculate the induced benefits of diverted and development traffic we have to estimate not only the fall in the transport cost but also the volume of traffic induced by the lower transport cost. Induced benefits can often be an important component of the benefits of a road improvement. The higher the elasticity of demand for transport, and the higher the fall in the transport cost, the more important will development benefits be. If we have data on different volumes of traffic and the associated levels of transport cost we can estimate the elasticity of the transport demand curve (or the slope, if the curve is linear). If we lack such data we could still estimate the elasticity of the development component (but not the diverted traffic component) of the demand for transport by estimating the underlying elasticities of demand and supply of the transported commodity in the trading regions.

72. The quantities mentioned in the previous paragraph are, however, frequently difficult to measure, particularly in underdeveloped countries. For example, cost savings of road users can seldom be directly measured, although rate changes may possibly give some indication. General knowledge of the effect of specific road improvements on road user costs, adjusted to local conditions, is a more satisfactory approach to this problem.1/ The surplus on induced traffic presents greater problems. Even conceptually, as discussed in this paper, there are complications if market imperfections in transport and distribution are significant. In practice, the problem is likely to be worse. The growth of traffic, and its breakdown between normal and induced traffic, is difficult to estimate. The simple measures of benefits from induced traffic based on changes in transport costs used in the earlier sections above, are infrequently, it would appear, a satisfactory guide to the surplus on induced traffic. The difficulties become

1/ See de Weille, op. cit.
even greater if a divergence between marginal social cost and benefits of transport from competing sources of supply, or by a competing mode, makes it necessary, as noted earlier, to make an estimate of the losses suffered by, say, the region or railway from which traffic is diverted.

73. It is clear, then, that conceptual clarity is a necessary, but not sufficient condition for plausible estimation of the benefits of a road improvement. The practical difficulties of estimation are obviously great. In some cases there may be good reasons for thinking that the road user savings, which can probably be measured with somewhat greater confidence, are the bulk of the estimate. But this is certainly no general rule. The development benefits may be quite important - in fact, the most relevant part for some road improvements. In cases where changes in transport costs give a good indication of the height of the "development triangle", the main issue is the volume of induced traffic, in relation to normal traffic. But in cases where the distortions in transport or distribution are serious, as may often be the case - a reasonable estimate of the benefits from development and diverted traffic and possible offsetting losses elsewhere cannot be made without explicitly considering explicitly the complications considered at some length in this paper. It should be admitted that in the present state of our knowledge, estimating the benefits of road investments is an art as well as a science.
APPENDIX A
(to Sections 2, 3 and 4)

I. Two-Regional Case

1. The analysis in Section 2 is derived from a simple linear model. We shall describe the model in this section. We assume that in the absence of any trade between region A and region B, the price of the commodity will be higher in A than in B. The minimum prohibitive transport cost which will prevent any movement of the commodity between the two regions equals this price difference. As the transport cost is lowered, the price in A will fall and the price in B will rise. But unless the transport cost falls to zero (free trade), the price in A will always be greater than the price in B. This means, of course, that A will always remain an importer from B. The improvement of the road between A and B will reduce the transport cost and establish a new lower price difference between A and B. Since we have equated the price difference to the transport cost it is at once clear that our definition of the transport cost is broader than usual. The cost of transportation is the cost of "door-to-door" delivery. The cost of transportation on the road is only a part, although probably the most important part, of the transport cost as we have defined it.

2. The model used in Section 2 is:

1. \[ D_A = a_A + b_A P_A \quad b_A < 0 \quad a_A > \alpha_A \]
2. \[ S_A = \kappa_A + \beta_A P_A \quad \beta_A > 0 \]
3. \[ D_B = a_B + b_B P_B \quad b_B < 0 \quad a_B > \alpha_B \]
4. \[ S_B = \kappa_B + \beta_B P_B \quad \beta_B > 0 \]
5. \[ D_A + D_B + S_A + S_B \]
6. \[ P_A = P_B = \theta_{AB} \quad \theta_{AB} \geq 0 \]

Notations:

- \( D \) = Demand
- \( S \) = Supply
- \( P \) = Price
- \( \theta_{AB} \) = Transport cost between A and B
Appendix A - Page 2 -

Notations (cont'd)

\( \alpha_A - a_A = H < 0 \)

\( \alpha_B - a_B = I < 0 \)

\( b_A - \beta_A = L < 0 \)

\( b_B - \beta_B = M < 0 \)

With no trade, \( P_A > P_B \), i.e., \( \frac{H}{L} > \frac{I}{M} \).

3. The above system can be solved to yield

7. \( \frac{A,B}{P_A} = \frac{H + I}{L + M} + \frac{M}{L + M} \theta_{AB} > 0 \)

8. \( \frac{A,B}{P_B} = \frac{H + I}{L + M} - \frac{L}{L + M} \theta_{AB} > 0 \)

9. \( \frac{A,B}{X_A^D} = \frac{L - HM}{L + M} + \frac{LM}{L + M} \theta_{AB} > 0 \)

10. \( \frac{A,B}{X_B^S} = \frac{A,B}{X_A^D} \)

where \( \frac{A,B}{P_A} \) = equilibrium price in A in the two-region (AB) case.

\( \frac{A,B}{P_B} \) = equilibrium price in B in the two-region (AB) case.

and,

\[ \begin{align*}
\frac{X}{A} &= \frac{D}{A} - \frac{S}{A} = T
\end{align*} \]

\[ \begin{align*}
\frac{S}{A} &= \frac{S}{A} - \frac{D}{B} = T
\end{align*} \]

\( \left\{ \begin{align*}
\text{equilibrium values}
\end{align*} \right. \)

4. Since, the volume of trade \( T_{AB} = \frac{A,B}{X_A^D} = \frac{A,B}{X_A} \), the transport demand curve is given by

11. \( T_{AB} = \frac{L + H M}{L + M} + \frac{L M}{L + M} \theta_{AB} \), and is shown below in Fig. I corresponding to Fig. II in the text.
Appendix A - Page 3 -

Figure 1

5. The slope of the curve is, from equation (11), \( \frac{LM}{L + M} \). Now,

\[
L = b_A - \beta_A
\]

\[
= \frac{d(D_A - S_A)}{dP_A}
\]

\[
= \frac{1}{P_A} \left[ \frac{D_A}{D_A - S_A} E(D_A) - \frac{S_A}{D_A - S_A} E(S_A) \right]
\]

\[
= \frac{1}{P_A} \left[ V_A E(D_A) - W_A E(S_A) \right]
\]

\[
= \frac{1}{P_A} \ell \text{ where } \ell \text{ is as defined in the text (para. 29).}
\]

The quantities \( P_A, D_A, S_A, V_A, W_A \) refer to the equilibrium magnitudes corresponding to the point at which the elasticity is to be taken. They should have been marked with an appropriate superscript to indicate this. We have not done so for the sake of notational simplicity. Similarly,

\[
M = \frac{1}{P_B} \cdot m, \text{ where } m \text{ is as defined in the text (para. 29).}
\]

6. The price elasticity of the transport demand curve is given by

\[
\frac{\Theta_{AB}}{T_{AB}} \cdot \frac{LM}{L + M} = E(T_{AB}).
\]

Substituting for \( L \) and \( M \), and noting that \( D_A - S_A = S_B - D_B \), we get the equation (1) in the text (para. 29).
II. Three-Regional Case

7. The model used in Section 3 in the text is given by equations 1-4 of the previous model, combined with the following equations:

5. \( D_C = a_C + b_C \)  
   \( b_C < 0 \)

6. \( S_C = \alpha_C + \beta_C \)  
   \( \beta_C > 0 \)  
   \( a_C > \alpha_C \)

7. \( D_A + D_B + D_C = S_A + S_B + S_C \)

8. \( P_A = P_B + \theta_{AB} \)  
   \( \theta_{AB} \geq 0 \)

9. \( P_A = P_C + \theta_{AC} \)  
   \( \theta_{AC} \geq 0 \)

\( (b_C - \beta_C) = N < 0 \)

\( (\alpha_C - a_C) = J < 0 \)

We assume that, without any trade, \( P_A > P_C > P_B \), i.e., \( \frac{H}{L} > \frac{J}{N} > \frac{I}{M} \).

8. Since we are interested only in the case where C is an exporter to A, we shall make an assumption which will ensure this. This assumption will guarantee that C enters trading as an exporter to A and remains an exporter. This assumption is:

\[ \theta_{AC} = \theta_{AC} = \left| \begin{array}{c} \frac{A_B}{A_C} \end{array} \right| \quad -\frac{J}{N} = \frac{H + I}{L + M} - \frac{J}{N} \]

where \( P_A \)  
\( \theta_{AB} = 0 \)

is the value of \( P_A \) when there is trade between A and B only, without any transport cost between A and B. \( \frac{J}{N} \) is the value of \( P_C \) that would rule if C did not enter trading. In other words, we assume that the transport cost \( \theta_{AC} \), between A and C, remains constant at a level given by the difference between the free trade price in A (without participation by C) and the isolation price in C. This is a sufficient condition, not a necessary one. The necessary condition is weaker. But this assumption simplifies the analysis without changing the basic conclusions.
The solutions are, using $\bar{\theta}_{AC} = \frac{H + I}{L + M} - \frac{J}{N}$,

9. $\bar{\theta}_{AC} = \frac{H + I}{L + M} + \frac{M}{L + M + N} \theta_{AB}$

10. $\bar{P}_{A} = \frac{H + I}{L + M} + \frac{M}{L + M + N} \theta_{AB}$

11. $\bar{P}_{B} = \frac{H + I}{L + M} - \frac{(L + N)}{L + M + N} \theta_{AB}$

12. $\bar{P}_{C} = \frac{J}{N} + \frac{M}{L + M + N} \theta_{AB}$

13. $\bar{X}_{A} = \frac{IL - HM}{L + M} + \frac{LM}{L + M + N} \theta_{AB} > 0$

14. $\bar{X}_{B} = \frac{HM - IL}{L + M} - \frac{\theta_{AB} M(L + N)}{L + M + N} < 0$

15. $\bar{X}_{C} = \frac{MN}{L + M + N} \theta_{AB} < 0$

Volume of trade, $T = T_{AB} + T_{AC} = \bar{X}_{A}^{S} + \bar{X}_{C}^{S} = \bar{X}_{A}^{D}$

10. From this model, we can derive relationships between $T_{AB}$ and $\theta_{AB}$, $T_{AC}$ and $\theta_{AB}$, and $T_{AB} + T_{AC} = T$ and $\theta_{AB}$. The relationship between $\theta_{AB}$ and $T_{AC}$ ($= \bar{X}_{C}^{S}$) is shown below in Fig. II. This is derived from equation (15) above, noting that at the level $\theta_{AB} = \omega = \frac{(HM - IL) (L + M + N)}{M(L + N) (L + M)}$, $T_{AC}$ equals $T$ since trade between $A$ and $B$ disappears ($T_{AB} = 0$).

Figure II

\[ \omega = \frac{(HM - IL) (L + M + N)}{M(L + N) (L + M)} \]
11. The relationship between $T_{AB}$ and $\theta_{AB}$, the one used in the text (para. 36) is given by equation (14) above. This is shown below in Fig. III.

Figure III

12. The relationship between $T$ and $\theta_{AB}$ is shown below in Fig. IV.

Figure IV
13. The elasticity of the curve in Fig. III is derived analogously to the previous case. The slope is given by $\frac{M(L + N)}{L + M + N}$ from equation (14) above. We have, $E(T_{AB}) = \frac{\theta_{AB}}{T_{AB}} \cdot \frac{M(L + N)}{L + M + N}$. We have seen, that $L = \frac{f}{P_A}$, $M = \frac{m}{P_B}$. $N$ can be shown to be equal to $\frac{n}{P_C}$ where $n$ is as defined in the text (para. 37). Substituting for $L$, $M$, $N$, we get the equation (5) in the text (para. 37). This expression is, however, more complicated than the one in equation (1) (para. 29). The reason is simply that, in the case of equation (1), $D_A - S_A = S_B - D_B$, and hence, it was possible to achieve a reduction to a simpler form.

III. Rising Transport Cost

14. $\theta_{AB}$ was used as a parameter in both the Two-Regional and the Three-Regional model. We may consider $\theta_{AB}$ as an endogenous variable by adding an equation for the transport supply curve.

15. Let this equation be:

$$T_{AB} = g + h\theta_{AB}, \quad h > 0.$$ 

Using this in the first model (Appendix A, Section I) we get, using equations (6) and (8):

$$\tilde{\theta}_{AB} = \frac{g(L + M) - (LI - HM)}{LM - h(L + M)}$$

as the equilibrium value of $\theta_{AB}$. Using the equations in the second model (Appendix A, Section II) we get, using equations (8) and (11):

$$\tilde{\theta}_{AB} = \frac{g(L + M) - (LI - HM)}{M(L + N) - h(L + M + N)} \cdot \frac{L + M + N}{L + N}$$

as the equilibrium value of $\theta_{AB}$. Using these values of $\tilde{\theta}_{AB}$ we can eliminate $\theta_{AB}$ from the equations (7-10) (Section I) and equations (10-15) in (Section II) getting new equilibrium values of the variables concerned. Shifts in the transport supply curve will be represented by changes in the value of the parameter $g$.

IV. Variation in the Transport Cost between A and C, $\theta_{AC}$

16. We have mentioned in paragraph 14 of the text that neither our conclusions, nor our method need be significantly modified if we relax the assumption that the transport cost between A and C, $\theta_{AC}$, is constant. We wish to show why this is true in this section.
17. Constancy of the transport cost, $\theta_{AC}$, can be justified by assuming that the supply curve of transport services between A and C is infinitely elastic - horizontal, at least in the relevant range. However, if the supply curve is positively sloped then $\theta_{AC}$ will fall when the demand for transport between A and C falls. That is, when $\theta_{AB}$ falls due to a road improvement, $\theta_{AC}$ will fall too. This fall in $\theta_{AC}$ will shift the demand curve for transport between A and B to the left causing a further fall in $\theta_{AB}$ if the supply curve of transport between A and B is also positively sloped. In the new equilibrium, after the interactions end we will have a lower $\theta_{AB}$, a lower $\theta_{AC}$, a lower $T_{AC}$ and probably a higher $T_{AB}$. This is illustrated below in Fig. V.

Figure V

18. In Fig. V above, $(\theta_{AB}^0, \theta_{AC}^0, T_{AC}^0, T_{AB}^0)$ is the set of values in initial equilibrium. $S_{AB}^0$, the supply curve between A and B, falls to $S_{AB}^1$ due to the improvement of the road between A and B. $(\theta_{AB}^1, \theta_{AC}^1, T_{AC}^1, T_{AB}^1)$ is the set of values in the new equilibrium. Both the demand curves have shifted to the left. $\theta_{AB}$ and $\theta_{AC}$ are lower than before. The traffic between A and C has also fallen. We have assumed here that traffic between A and B has increased. We might similarly conceptualize a series of shifts in $S_{AB}$.
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giving rise to a series of new equilibrium points. The locus of all
the equilibrium values of \( \theta_{AB} \) is LL, as drawn in Fig. V above. LL could
be positively or negatively sloped, or be vertical, depending on the
specific forms given to the demand and supply functions. The locus of
the equilibrium values of \( \theta_{AC} \), on the other hand is the supply curve \( S_{AC} \),
since \( S_{AC} \) does not shift (the road between A and C is not improved).

19. We can devise measures of the surpluses enjoyed by the consumers
and producers of the commodity in terms of Fig. V, exactly as before
(footnote 1, para. 31 and footnote 1, para. 38). Referring to Fig. III
in the text, the net gain from the point of view of consumers and producers
of the commodity is given by:

\[
\text{Net gain} = \frac{1}{2} \Delta P_A \left[ T_{AB}^0 + T_{AB}^1 + T_{AC}^0 + T_{AC}^1 \right]
+ \frac{1}{2} \Delta P_B \left[ T_{AB}^0 + T_{AB}^1 \right] - \frac{1}{2} \Delta P_C \left[ T_{AC}^0 + T_{AC}^1 \right]
\]

The term \( \frac{1}{2} \Delta P_A \left[ T_{AB}^0 + T_{AB}^1 + T_{AC}^0 + T_{AC}^1 \right] \) is the net gain in consumers'
surplus in region A (area ABCD in Fig. III). The term \( \frac{1}{2} \Delta P_B \left[ T_{AB}^0 + T_{AB}^1 \right] \)
is the net gain in producers' surplus in region B (area JIGH in Fig. III)
and the term \( \frac{1}{2} \Delta P_C \left[ T_{AC}^0 + T_{AC}^1 \right] \) is the loss of producers' surplus in region
C (area MNQR in Fig. III). In this case, we have \( \Delta P_A + \Delta P_B = \Delta \theta_{AB} \) and
\( \Delta P_A - \Delta P_C = \Delta \theta_{AC} \). Hence, the net gain can be written as:

\[
\text{Net gain} = \frac{1}{2} \Delta \theta_{AC} \left[ T_{AB}^0 + T_{AB}^1 \right] + \frac{1}{2} \Delta \theta_{AC} \left[ T_{AC}^0 + T_{AC}^1 \right]
\]

Looking at Fig. V above, we can see that

\[
\text{area QSUT} = \text{area QRUT} + \text{area RSU}
= \frac{1}{2} \Delta \theta_{AC} \left[ T_{AC}^0 + T_{AC}^1 \right]
\]

and

\[
\text{area VWXZ} = \text{area WYZ} + \text{area WXY}
= \frac{1}{2} \Delta \theta_{AB} \left[ T_{AB}^0 + T_{AB}^1 \right]
\]

We have thus obtained measures of the net benefit in terms of the demand
and supply functions of transport between A and B and between A and C.

20. We saw before that, with constant \( \theta_{AC} \), the net gain is entirely
reflected by the change in area under the demand curve for transport between
A and B. A little reflection will show that in the present case, where \( \theta_{AC} \)
depends on the volume of transport \( T_{AC} \), the net gain is similarly shown by
the change in the area under the locus LL, i.e., by area VWXYZ. The reason is that the producers of the transport service between A and C have lost a surplus exactly equal to QSUT. Taking this loss of producers' surplus into account we are left with the area VWXYZ as the net gain. The only difference in this case is that the net gain is now measured by the change in the area under the locus LL (VWXYZ) whereas before it was change in the area under the non-shifting demand curve (other prices being constant) for transport between A and B. This calls for only a minor reinterpretation of the statement that "the net gain is measured by the change in the area under the demand curve for transport between A and B".

21. Of course, in order to measure total net gain it is clear from Fig. V above, that we still have to account for the change in the surplus of the producers of the transport services between A and B. VWXYZ has to be corrected by the net increase of producers' surplus (Z² - Z₁). But this case has been fully discussed in Section IV under the title "Congestion". There is nothing to add to that discussion here except to mention that the demand curve has to be replaced by the locus LL.

22. The reader may wonder why the introduction of interrelated demand functions in this case does not result in the same kind of problems as we faced in the road-rail diversion problem (paras. 52, 53, Section V). The reason is that in Sections 2 and 3 (described by the models in Sections I and II of this Appendix) the transport services between A and B and between A and C were not treated as final consumer goods. The demand for transport between A and B and between A and C were derived demands. The transport services did not enter into the consumers' utility function directly. Thus they did not yield any consumers' surpluses by themselves. The changes in the surpluses of consumers' and producers of the commodity were measured by the changes in the area under the demand curve for transport between A and B. This is a convenient measure which saves us from considering the demand and supply curves of the commodity directly.

23. In the road-rail diversion case, however, road and rail were treated as competing final consumer goods which give utility to the consumers. The road-rail diversion problem cannot be handled in terms of the models in Sections I and II of this Appendix as they stand now. We have to introduce separate demand equations for road and rail services in those models. The models, then, will become three-commodity models instead of being one-commodity models as they are now. In other words, we shall have to allow for the possibility that, say, road services may compete in consumption with not only rail services but also with the commodity itself. The demand for the commodity will be a function, not only of its price but also of the prices of road and rail services. However, when the road and rail services are not related in consumption to the commodity then we can use the methods discussed in Section 5 to compute changes in consumers' surpluses.
APPENDIX B
(to Section 5)

I. Price of Rail Services Constant

1. In Section 5 (paras. 50 and 51) we discussed the road-rail diversion problem on the assumption that rail prices do not change in response to changes in road prices. We asserted at that time that, in a case where the prices of related commodities remain constant, the net change in the consumers' surplus due to a fall in the road price is given by the change in the area under the demand curve for road. We shall prove this proposition in this appendix. Before we do so we shall make a few comments regarding the concept of consumers' surplus.

2. The demand curve of a commodity, $X_1$, is usually drawn with respect to changes in the price of that commodity. The position of the demand curve is uniquely given if the commodity is not related to any other commodity or if the prices of related commodities are held constant when the price of the commodity changes. When the price of the commodity falls and the demand for it increases, the change in the area under the demand curve (its position being uniquely given) is regarded as the change in consumer surplus. We cannot measure changes in consumers' surpluses in this way if the prices of related commodities are allowed to vary in response (since the demand curve for $X_1$ will shift its position). How to measure consumers' surpluses in such a case is the subject of the next section. In this section we assume that the demand curve for $X_1$ has a unique position (the prices of related commodities do not change).

3. The increase in consumers' surplus is a measure of the increase in welfare or utility enjoyed by the consumers when the price of the commodity falls. Our primary concern is to measure the change in utility (for this we must, of course, assume that utility is cardinally measurable). The technique of consumers' surplus is a technique for measuring the change in utility. The use of this technique is valid provided certain conditions are fulfilled. In the course of our proof we shall mention the required conditions. Under certain conditions the consumer surplus technique will accurately measure the change in utility. Again, under certain conditions, the change in the area under the demand curve will accurately measure the change in consumers' surplus. If all the conditions hold and if the demand curve is defined appropriately, then the change in utility will be measured by the change in the area under the demand curve.

4. Suppose there are $n$ goods $X_1, \ldots, X_n$. Their prices are $P_1, \ldots, P_n$. We shall consider the change in utility when the price of only one commodity, $X_1$, changes, the other prices,

\[ \frac{1}{n} \text{ For a discussion of this and related matters, see P. Samuelson, "Constancy of the Marginal Utility of Income," Studies in Mathematical Economics and Econometrics. (University of Chicago, 1942).} \]
P_2, \ldots, P_n$, remaining unchanged. When the price of \( X_1 \), \( P_1 \), changes, the quantities of the other commodities will change, i.e., \( X_2, \ldots, X_n \) will change. One can immediately see that it is a more general case of the road–rail diversion problem. \( X_1 \) may be regarded as road services. \( X_2, \ldots, X_n \), then, are the quantities of all the related commodities including rail.

5. Let \( P_1^0, P_2^0, \ldots, P_n^0 \) be the initial prices of the \( n \) commodities. Since only \( P_1 \) changes, \( P_1^1, P_2^0, \ldots, P_n^0 \) is the new set of prices. Similarly, let \( X_1^0, X_2^0, \ldots, X_n^0 \) be the initial quantities of the \( n \) commodities. Since all quantities change, \( X_1^1, X_2^1, \ldots, X_n^1 \) is the new set of quantities.

6. We now have to define a cardinal utility function. Cardinality implies that we can quantify the changes in utility. Let the utility function be \( U = U(X_1, \ldots, X_n) \). The initial level of utility is given by \( U^0 = U(X_1^0, \ldots, X_n^0) \) and the new level of utility is given by \( U^1 = U(X_1^1, \ldots, X_n^1) \). We also have a budget constraint implying that the total money expenditure must be equal to total money income. The budget constraint states that \( \sum_{i=1}^{n} P_i X_i - I = 0 \) where \( I \) is the money income. Maximizing the utility function subject to the budget constraint, we get \( P_1 \lambda = \frac{\partial U}{\partial X_1}, \ i = 1 \ldots, n \). \( \lambda \) is called the marginal utility of income and is a function of all prices and money income. In order to use the concept of consumer surplus we must assume that the marginal utility of income is constant with respect to changes in all prices excepting one, say, \( P_n \), and with respect to changes in money income, \( I \).

Thus, we get:

\[
\frac{\partial \lambda}{\partial P_i} = 0 \quad i \neq n
\]

\[
\frac{\partial \lambda}{\partial P_n} \neq 0
\]

\[
\frac{\partial \lambda}{\partial I} = 0
\]
7. We have,

\[ u(x^1) - u(x^0) = \int_{P_1^0}^{P_1} \frac{dU}{dP_1} \, dP_1 \]

\[ = \int_{P_1^0}^{P_1} \left\{ n \sum_{i=1}^{n} \frac{\partial U}{\partial x_i} \frac{\partial x_i}{\partial P_1} \right\} \, dP_1 \]

[using the equalities \( P_i \lambda = \frac{\partial U}{\partial x_i} \) all \( i \)]

\[ = \int_{P_1^0}^{P_1} \lambda \left\{ \sum_{i=1}^{n} P_i \frac{\partial x_i}{\partial P_1} \right\} \, dP_1 \]

[using the budget constraint]

\[ = -\int_{P_1^0}^{P_1} \lambda x_1 \, dP_1 \]

\[ = -\lambda \int_{P_1^0}^{P_1} x_1 \, dP_1 \]

\[ = -\lambda D \text{ where } D \text{ is the area under the demand curve, between } P_1^0 \text{ and } P_1, \text{ for } x_1. \text{ Our assumptions imply that the all-or-none demand curve, the ordinary demand curve and the Hicks-compensated demand curve coincide. Therefore, } D = \left[ -\int_{P_1^0}^{P_1} x_1 \, dP_1 \right] \text{ is the change in} \]
consumer surplus under the demand curve for $X_1$. This measures the total change in utility in this case. Hence, to compute the total change in utility we only have to take into account the change in area under the demand curve of the good whose price has fallen.

II. Price of Rail Services Variable

8. In this appendix we show how the change in consumers surplus can be measured mathematically when the price of rail changes in response to changes in the price of road. We shall also show a diagrammatic correspondence to the mathematical measure. This case and the diagram have been discussed in the text, paragraphs 50-51.

9. We have the joint demand functions

$$X_R = F(P_R, P_L); \text{ demand for road services}$$
$$X_L = G(P_R, P_L); \text{ demand for rail services}$$

Inverting them

$$P_R = H(X_R, X_L); P_R = \text{ price of road services}$$
$$P_L = I(X_R, X_L); P_L = \text{ price of rail services}$$

Then the total willingness to pay $W$ is a sum of the line integrals,

$$W^o = \int_{(0,0)}^{(X^o_R, X^o_L)} H(X_R, X_L) \, dX_R + \int_{(0,0)}^{(X^o_R, X^o_L)} I(X_R, X_L) \, dX_L.$$  

By independence of path,

$$W^o = \int_0^{X^o_R} H(X_R, 0) \, dX_R + \int_0^{X^o_L} I(X^o_R, X_L) \, dX_L.$$  

10. The equation above is a mathematical measure of the consumers' willingness to pay. If we subtract the amount the consumers actually pay we get the consumers' surplus. The total willingness to pay has been computed for the situation where the prices of road is $P^o_R$, the price of rail is $P^o_L$, the quantity of road services sold is $X^o_R$, and the quantity of rail services sold is $X^o_L$. If the price of road falls, we shall get another
set of values, $P^1_R, P^1_L, x^1_R, x^1_L$, in the new equilibrium. With this new set of values we can again measure the willingness to pay. Call the new willingness to pay $W^1$. $(W^1 - W^0)$, then, represents the change in the willingness to pay from the initial situation to the new situation. If $C^0$ is the cost incurred by the consumers in the initial situation, then the consumers' surplus in the initial situation ($S^0$) is given by $S^0 = W^0 - C^0$. Similarly, if $C^1$ is the cost incurred by the consumers in the new situation, the consumers surplus ($S^1$) in the new situation is given by $S^1 = W^1 - C^1$. $(S^1 - S^0)$, then, gives the change in the consumers' surplus. Since it is easy to know $C^0$ and $C^1$, computing the change in consumers' surplus is easy when we have computed the willingness to pay in the two situations.

11. The equation

$$W^0 = \int_0^{x^0_R} H(x_R, 0) \, dx_R + \int_0^{x^0_L} I(x^0_R, x_L) \, dx_L$$

has a simple diagrammatic interpretation. The diagrammatic representation was given in the text and is repeated here, below.

The total willingness to pay is the sum of the shaded areas above. The diagram on the left corresponds to $\int_0^{x^0_R} H(x_R, 0) \, dx_R$ and the diagram on the right corresponds to $\int_0^{x^0_L} I(x^0_R, x_L) \, dx_L$.

12. It is to be noted that the case treated in Section I of this appendix, where the price of rail services remains constant when road prices change, is a particular case of the more general case dealt with
here. The method of this section can be used also to treat the special case of Section I. It is important, however, to keep in mind the difference between the definition of the demand curve in Section I, where other prices are assumed to remain constant, and the definitions used in this section.