On
Projects,
Transportation Projects
and the Mendoza (Argentina) - Los Andes (Chile) Transportation Corridor

By

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Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in Civil and Environmental Engineering
at the
Massachusetts Institute of Technology

September 1996

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JAN 29 1997
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Submitted to the Department of Civil and Environmental Engineering
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ABSTRACT

An evaluation framework for projects in general and transportation infrastructure projects in particular is developed. The focus is on deriving concrete decision criteria based on first principles and minimizing forecasting required. Arguments are derived from finance theory, economics, organization theory and the cognitive sciences. The current trend of providing transportation infrastructure projects privately is questioned. It is shown that under certain and prevalent conditions, governments ought not perceive riskiness of outcomes as a cost.

The framework is applied to a proposed 26 km tunnel through the Andes, improving the transportation corridor Mendoza (Argentina) - Los Andes (Chile), which is part of the so-called Bi-Oceanic Corridor connecting Buenos Aires and Santiago (de Chile). Interest in this project has recently increased as Chile has joined the Mercosur trade alliance. The analysis is largely based on an extensive feasibility study. Six technological options for the tunnel are considered. Based on the available information the optimal technology is determined and scenarios for optimal timing are developed. As starting construction is found to be economically promising in the short term, it is argued that further research into technology for and demand of the transportation corridor is indicated and that a yearly analysis ought to be conducted.

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ACKNOWLEDGEMENTS

I would like to thank Prof. Joseph Sussman for his reluctance to accept earlier and premature versions of this thesis.

I would like to thank Prof. Herbert Einstein for providing me with some technical understanding of tunneling and for his precise criticism.

I would like to thank Mr. Martin Boefer of Geoconsult and Elma Montana of CIT for their extraordinary support in data collection.
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INTRODUCTION AND ORGANIZATION OF THE THESIS

This year Chile has joined Argentina, Brazil and other South American countries in the common market referred to as Mercosur. The degree of integration in Mercosur as yet falls considerably short of, for instance, the European Union. Nevertheless the Mercosur agreements signal the determination of all members to reduce, and in the longer run abolish, existing barriers to trade among members and to reduce barriers to trade with other countries. Considering the protectionist history of South American countries, a large potential for trade is to be expected. This is particularly the case for trade between Chile and Argentina, who were at war as recently as 1982.

Trade requires cheap and reliable transportation. The transportation infrastructure currently in place is not designed to exploit the trade potential created by Mercosur. It is designed for limited trade as a consequence of restrictive trade policies prevalent until recently. It follows that the transportation infrastructure needs to be re-designed to optimally implement the newly created trade potential.

One critical impediment to trade is the poor transportation infrastructure across the Andes between Argentina and Chile. The major transportation link, via a mountain pass at an altitude of 3185 m, has low capacity due to large gradients and hairpin curves; it is frequently closed during the winter. In particular, this means that the main transportation link between the capitals and economic centres of Argentina and Chile, Buenos Aires and Santiago, respectively, is expensive and unreliable. This transportation link is known as the Bi-Oceanic Corridor.

The low quality of the Bi-Oceanic Corridor affects the following traffic flows negatively: International traffic between Chile and Argentina; intercontinental traffic, specifically Chile with the European Union and Argentina with the Pacific Rim and inter-oceanic traffic, i.e. traffic connecting ports on the Atlantic Ocean, in particular Buenos Aires and
Montevideo, with ports on the Pacific Ocean, in particular Valparaiso. It follows that there are large benefits to be expected from improving the transportation link.

It has been proposed to improve the link by building a 26 km long "low altitude" tunnel with a maximum altitude of the route of 2760 m vs. the present 3185 m, which would increase capacity and improve reliability. Such tunnels are expensive to build.

The crucial question is whether the benefits of such an undertaking justify the costs. The purpose of this thesis, then, is to contribute to the answer of this question for this particular project and to contribute to the answer of this question for projects in general. The latter is conducted in Part I of the paper, comprising chapters 1 and 2. The former is conducted in Part II of the paper, comprising chapters 3-7.

In Chapter 1 we develop an analytic framework for projects in general and consider implications of time, risk and the principal-agent relationship for the design and evaluation of projects. In Chapter 2 we focus our attention on transportation infrastructure projects. We investigate how to optimally operate transportation infrastructure with respect to ownership and pricing. We develop decision principles for choosing the optimal technology and the optimal timing of investment, placing much emphasis on the minimization of forecasting requirements in order to avoid making investment decisions on the basis of unconvincing long term forecasts.

In the remaining chapters, comprising Part II, we apply the framework developed to the particular tunnel project mentioned above to contribute to the answer to the question of whether the benefits justify the costs. The main source document for our analysis is a feasibility study of the tunnel project commissioned by the Argentinian and Chilean governments and completed in 1995. In Chapter 3 a description of the project is given. In Chapter 4 the technological options for improving the link are described and their cost structure analyzed. In Chapter 5 the benefits are estimated. In Chapter 6 we synthesize benefits and costs to determine the optimal technological option and timing of investment on the basis of the assumptions in the model. We conduct a sensitivity analysis to
determine which assumptions, especially, ought to be questioned. The paper concludes with a discussion of the results in Chapter 7.

The paper relies substantially on material provided in Figures and in the Appendix. This is particularly true for the second part. The system of notation of the Appendix and for Figures parallels the numbering of chapters in the main text: Complementary material to chapter x.y.z is contained in Appendix x.y.z or in the text in Figure x.y.z.
PART I: ON THE EVALUATION AND DESIGN OF PROJECTS
CHAPTER 1 : GENERAL PROPERTIES OF PROJECTS

1.1 INTRODUCTION AND A STYLIZED MODEL

Everybody agrees that good projects ought to be done and bad projects ought not to be done. This is a truism or perhaps even a tautology such as all bachelors are not married. Disagreement sets in on the question of what constitutes a good project and what not, in general and in particular.

The attributes of a project supposedly underlying the final good/bad verdict are many and disparate. It follows that project appraisal is a complex undertaking.

It is a conceptual point that complexity is only dealt with in a non-arbitrary way by analysis and synthesis: Analyze the projects into parts which are amenable for evaluation and then synthesize the evaluations to arrive at a final verdict. In particular the assumptions made and inferences from the assumptions drawn in the process ought to be clearly stated.

A sufficient justification for conducting such a transparent analysis of projects is its beneficial effect on debates about projects. Firstly, it enables disagreeing parties to achieve second order agreement, i.e. to agree on what they actually disagree about. Secondly, it is instrumental in finding ways to resolve disagreement. In addition it may point out ways to optimize the design of a given project.

The goal of Part I of the thesis, then, is to contribute to the methodology for obtaining such a transparent analysis. The discussion draws on the existing body of theory developed under the headings of cost-benefit analysis and project evaluation and design.

The contributions of Part I of the thesis to the existing body of theory are:
1. Deriving prevalent methods in cost-benefit analysis of projects based on first principles;

2. Applying findings in organization theory to the design of projects;

3. Defending cost-benefit analysis against the criticism that it does not consider all that is required to make an investment decision;

4. Applying microeconomic theory to question the trend of private transportation infrastructure projects;

5. Elaborating on a decision principle for transportation projects that only requires forecasting states of affairs at the start of operations of the project rather than forecasting the states of affairs for the whole life of the project.

In this section, we begin by developing a highly simplified model of a project. In the following sections the simplifying assumptions will be dropped and realism, thereby, added.

Conventionally, a project is understood to be an option that is different from the option to continue with how things have been done or not so, the status quo option. In deciding between the two options - implementing the project or continuing the status quo, we are, in effect, deciding between two possible worlds - one with and the other without the project. The question then is how to compare the two possible worlds.

A project is an entity which requires inputs and produces outputs. Inputs and outputs affect different entities (e.g. individuals, organizations) positively or negatively (or not at all). Positive effects are measured as cash inflows or benefits and negative effects as cash

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1 We will conveniently refer to the possible world projected were the option implemented as “in the so and so option”.

12
outflows or costs of the project from that entity’s perspective. Net benefits are equal to benefits minus costs. Derivatively, costs and benefits of a collection of entities may be summed to obtain the net benefit for that collective.

From the perspective of a particular entity a project is good if and only if the net benefits accrued are greater or equal to that of the status quo.

In order to appraise a project from the collective perspective the following predicates are useful: A project P is Pareto efficient if and only if every affected entity has net benefits larger than those of the status quo. A project P is efficient if and only if the sum of the net benefits of the entities affected is larger than those of the status quo.

Unclouded by details the input/output model of projects suggests the following principle:

P1 Choose efficient projects.

This principle follows readily from the premise that more good is preferred to less good or, in collective language, more welfare is preferred to less welfare. To illustrate the point consider the following homey instance of the principle: Suppose Jim, a ten year old boy, is offered the following deal by his mother: If you mow the lawn then you can go to the zoo. Suppose further that Jim dislikes lawn mowing more than he likes going to the zoo. It then follows that if Jim was rational we would expect him to turn down the offer. The underlying reasoning of that verdict, presumably, is that he receives less benefits than he incurs cost, which is precisely what principle P1 claims. A drastic way to describe what is happening if he accepts the offer is to say that he is destroying value.

---

2 This is sometimes referred to as potentially Pareto efficient.
3 A principle is or is equivalent to a conditional statement of some general applicability: If such and such is the case then such and such is or ought to be done or believed.
4 Is the proposition “more good is preferred to less good” capable of being justified or is it to be regarded as a proposition that is self-evidently true on the basis of which other propositions may be justified but not vice versa (nothing is as certain than that this proposition is true) - a so called first principle? I am taking it as sufficiently self-evident to serve the function of a premiss.
The decision principle is readily adapted to the case of more than two options: Consider a case in which there is a multitude of different ways to do a project. From a decision-making point of view, this is equivalent to saying that there is a multitude of different projects, though this is somewhat stretching everyday usage of the term project. In order to avoid neologisms let us refer to such a case as to a project for which there are different options for realization. Including the status quo option this case, then, is equivalent to choosing one of a set of different options and the principle, call it $P_1^*$, is:

$P_1^*$ Choose the option that maximizes net benefits.

The following is an argument designed to show that $P_1^*$ follows from $P_1$: Suppose there are $n$ realizations of the project, Option 1 to Option $n$, with $n$ a natural number or infinite. We have to show that applying principle $P_1$ or $P_1^*$ leads to the same choice. Suppose without loss of generality that Option $k$ maximizes net benefits. Clearly, applying $P_1^*$ leads to Option $k$. Does applying principle $P_1$ also lead to Option $k$? Yes, if the decision maker is willing and able to think conditionally. Suppose Option $j$ is efficient relative to the status quo and has less net benefits than Option $k$. Then, Option $j$, once chosen, is the status quo option and directly, or after a repetition of the procedure, Option $k$ is chosen as it is then efficient relative to the "status quo option". Quod erat demonstrandum. This argument also shows that the status quo option has no special status relative to the other options from a decision making perspective.

In the remainder let us drop one more assumption so far implicitly made and discuss the implications of doing so. So far we have depicted the decision problem as choosing among a given set of options. However there rarely are binding constraints or at least there are enough dimensions without them such that new and better options could be created. We juxtapose a static versus a dynamic approach to project evaluation: The former is characterised by parts of the project that have an instrumental function dictating the options to be evaluated relative to the substantive goal: creating net benefit. The

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5 The status quo option, though, has one intrinsic advantage over the non-status quo options: Its net benefits are known with a higher degree of certainty (i.e. less variance) as simple induction is available.
latter is characterised by an iterative process in which, directed towards the substantive goal, the options are formulated, evaluated and reformulated\(^6\). It appears that the process in the dynamic approach is likely to yield better projects and may therefore be referred to as optimization. This insight then motivates emphasizing the dynamic process in the formulation of our decision principle by rephrasing principle \(P^*\) into:

\[
P^{**} \quad \text{Projects should be optimized (Choose optimal project).}
\]

Let us illustrate this principle by harking back to Jim. Suppose that Jim likes going to the zoo more than he dislikes mowing the lawn. Suppose further, though, that he dislikes doing the dishes less than mowing the lawn and that his mother would accept a zoo for doing the dishes deal. Clearly Jim ought to accept that deal, which is consistent with what \(P^{**}\) would tell him to do.

So far we have been concerned with the concept of efficiency. We have defended the decision principle to choose efficient projects and investigated its implications. Let us now consider decision principles involving the concept of Pareto efficiency. Is there a case to be made for transforming efficient projects into Pareto efficient projects, i.e. to transform a project which is optimal with respect to the aggregate of the affected entities into a project in which each entity is at least better off than in the status quo? In other words should we apply the following principle?

\[
P^2 \quad \text{Efficient projects should be transformed into Pareto efficient projects.}
\]

If the efficient project is also Pareto efficient then both decision principles lead to the same choice. Unfortunately, conceptually and often enough in reality the decision principles \(P^1\) and \(P^2\) are not equivalent, i.e. they prescribe different choices. We will discuss ways to harmonize \(P^2\) with \(P^1\) in the next section. The following are two thoughts to motivate thinking about Pareto efficiency.

\(^6\) Clearly, these are the two poles of a continuum.
The second principle, P2, may be argued for by appeal to justice by the way of an example: It is right to compensate the owner of a plot of land that is to be used for a new airport. What, however, does compensation mean? Is it the price of the land in the market? Using market prices leaves the owner worse off as he values the plot of land higher than market price (otherwise he would have sold it before).

There is one special case in which an argument for the transformation of an efficient to a more Pareto efficient project is available on pragmatic grounds: If an entity has a veto over the project, then the project ought to be designed such that it is good from said entity’s perspective.

Let us sum up the lessons of this model: The evaluation of projects is essentially perspectival. We distinguish between individual entities’ perspectives and collective perspectives of a project. In relation to a project an individual entity incurs net benefits (or net costs). Derivatively, the net benefits/costs of a collective are the sum of the individual entities net benefits/costs. Projects should be optimized relative to the pertinent perspective.

So far, our simple input/output model is not a helpful guide in the real world as it leaves important questions unanswered: What are the entities? What is “the pertinent” perspective? What are the relationships between perspectives? Does optimizing with respect to one perspective imply optimization from another perspective? What are the benefits/costs? It is to this questions that we now turn in a fairly general way. The discussion could also, in a loose sense, be described as dropping the simplifying assumptions in the above model one at a time. In Chapter 2 we will attempt to answer these questions in more detail with respect to a particular subset of projects of which most large scale infrastructure projects are a part, with the aim to develop an applicable framework.

\[7\] Hopefully the reader’s tolerance of platitudes has not been overtaxed so far. But going back to first principles generally is, as well as an effective way to focus matters, essentially dull: First principles are first principles because they are obvious.
Let us begin with project evaluation from one particular individual entity’s perspective: the potential private owner\(^8\) of the project. In order to determine net benefits or cost of the project, this owner adds what has to be paid for the inputs and what is received for the output. The prices paid and the prices charged are referred to as financial prices. Goods used and produced for which no financial prices exist are not considered. For instance, environmental degradation would enter as a cost only if the owner had to pay for it.

The analysis conducted by the owner is therefore also referred to as the financial analysis. For the owner the necessary and sufficient condition to implement a project is financial viability, i.e. positive net benefits in financial terms. It follows that a project is optimized relative to the owner’s perspective by maximizing financial returns.

As noted, the private owner’s perspective on a project is only one perspective. It is an important perspective for the following reasons: (1) If the project ought to be done privately then financial viability is a necessary condition; (2) If the project is done publically then it requires sufficient funding to be financially viable, for otherwise it is simply not going to survive and the investment is lost.

However, it is advisable even for a private owner to consider at least the perspectives of entities that have a veto power over the implementation of the project. This might be the perspective of a sufficiently negatively affected and powerful entity such as a grass roots movement or it might be the guardian of the interest of a collective such as the government in an economy. It is to the latter perspective that we now turn.

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\(^8\) We simplify here by assuming that the project is 100% equity financed. If the project is partly debt financed then the owner will regard the inflows of the debt as benefits and the repayment of principal and interest as a cost. The banker on the other hand, being interested in the general viability of the project, will consider the 100% equity financed perspective.
Let us now consider the project from the national economy as a widely studied representative of one possible collective.

We begin with goods for which markets exist. We study the project’s impact on the collective for each unit of good used or produced one at a time and then aggregate the costs and benefits. For each good we disaggregate the collective into suppliers and consumers of that good. We assume:

1. The price required for suppliers to be willing to supply that unit of a good measures the value of that unit to a supplier;

2. The willingness to pay of consumers to consume that unit of a given good measures the value of that unit of that good to the consumer.

With these assumptions in place we can determine the cost from the collective’s perspective of a given unit of input or output, the so-called economic opportunity cost of a unit of that good. The underlying idea is this: The economic opportunity cost of a unit of a good is the value of that unit in its’ best alternative use. The good might be for instance cement, labor, foreign exchange or capital.

Consider an input to the project. That input comes either from consumption foregone by other consumers or from increased production or from both, depending on the shape of the willingness to pay and willingness to supply curves. The total economic cost of an input to the project is, then, the sum of the cost of consumption foregone as measured by the demand curve and the cost of increased production as measured by the supply curve. Derivatively, the economic price or shadow price for a unit of that good used by the project is the quotient of total economic cost and number of units consumed by the project. Similarly, the output of the project either increases consumption or reduces production by other suppliers in that market. The total economic benefit of the output of the project is, then, the sum of the benefits of increased consumption as measured by the demand curve and the benefits of decreased production by other suppliers, i.e. resource
savings. Derivatively the economic price or shadow price for a unit of that good produced by the project is the quotient of total economic benefit and number of units produced by the project. The relationship between economic prices and financial prices is conventionally described by the quotient of economic price and financial price, referred to as the conversion factor for that good. Based on the financial prices observable in the market the economic price is then calculated by the product of conversion factor and financial price.

In the case that no markets exist for an effect of the project, or in other words in the case of externalities, mapping an impact into a dollar value is more contentious. Consider for instance the monetization of time savings, safety and the savings of life and impacts on the environment. Note, however and importantly, that in the absence of a dominant option, i.e. of one option being better than any other option with respect to all attributes (and other attributes), choosing an option implies a set of monetizations of the non-monetized attributes - and this condition is frequently satisfied. As transparency is a virtue we monetize the impacts explicitly. Conceptually, externalities are monetized by estimating individual’s willingness to pay to enjoy a positive externality or individual’s willingness to pay to avoid a negative externality.

Aggregating all economic benefits and costs, then, yields the net benefits of the project from the economic perspective. So from the economic perspective a project should be

9 Determining the economic opportunity cost of goods is technically more complicated in the presence of distortions in the markets or if the effect on a project of a market is large. The cases of small effects and market distortions are discussed in G. Jenkins, A. Harberger “Cost-Benefit Analysis of Investment Decisions” chapters 7 - 13, using price elasticities of supply and demand. Unfortunately, in the case that the effects of the project in a market is large elasticities by definition are not informative. It seems that the only available option is to determine the shape of the supply and demand curves over the relevant range.

10 The reasoning described is further explained and applied in Chapter 5.

11 “An externality is any valued impact (cost or benefit) resulting from any action (whether related to production or consumption) that affects someone who did not fully consent to it”, Source: D. Weimar, A. Vining “Policy Analysis” p. 57, Prentice Hall.

12 Articles on the evaluation of these impacts are to be found in R. Layard, S. Glaister “Cost-Benefit Analysis” p.235ff, CUP, by The MVA consultancy, S. Rosen, M.W. Jones-Lee, P. Dasgupta and K. Maier, respectively.

13 See Chapter 1.6.
implemented if net economic benefits are positive. Derivatively, a project is optimized by maximizing economic returns.

Note that in the economic analysis, the benefits and costs accruing to different entities in society are simply summed to obtain the net benefits. In other words, it is assumed that the value of a dollar is independent of to whom it accrues. This assumption is prima facie inconsistent with the common belief that an extra benefit to a needy man has more value than an extra benefit to a rich man. One approach to incorporate this belief into the economic analysis is to drop the assumption of “a dollar is a dollar” and to calculate net benefits of a project by weighing the benefits and costs as a function of to which entity they accrue, with the weights being positively correlated with the entity’s neediness. This approach is referred to as the distributional weights approach.

There are potent pragmatic objections to this approach. I will argue against it on two grounds: (1) Using distributional weights consistently in project evaluation has an implication that is inconsistent with beliefs that are both strong and prevalent: If transfer of wealth could be accomplished without loss and the rich had lower distributional weights than the poor then wealth ought to be redistributed until wealth among members of the society is equalized. The conclusion does not go well with beliefs such as wealth ought to be positively correlated to achievement.

(2) I take it that, by and large, society’s altruism to subsidize the less fortunate does not extend to in-money subsidies (as by applying a higher weight to monetary benefits accruing to them) but rather to in-kind subsidies in which case distributional weights is misguided as it does not account for whether the money so transferred is spent on, say, a

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14 In the literature this approach is discussed using the concept of utility. The idea, then, is to calculate benefits in terms of the utility the recipient perceives rather than the dollar amount he receives. And as a poor person perceives higher extra utility for extra money the benefit calculated for him ought to be higher. For a discussion: E. Stockey, R. Zeckhauser “A Primer for Policy Analysis” chapter 12, Norton.
16 This is a simplified and less realistic version of an argument advanced in: A. Harberger “Basic Needs versus Distributional Weights in Social Cost-Benefit Analysis.”
new television set or on education for the children. This thought, then, leads to a second approach to incorporate distributional impacts of a project in the economic analysis: For basic needs, such as housing, that are satisfied as a consequence of the project a premium is added over and above the willingness to pay of the consumer ("the poor"). The premium is based on the degree of altruism in society. Technically speaking, the satisfaction of a basic need is treated as a positive externality. This approach is referred as the basic needs approach. Note that in the basic needs approach the, assumption that the value of dollar is independent of to whom it accrues is valid. Note that the basic needs approach incorporates altruism without unpalatable implications. Thus, the basic needs approach is the method of choice to incorporate distributional impacts in the evaluation of a project and ought to be conducted to complement the economic analysis.

The basic needs approach indicates a method for harmonizing the principle P1 (Choose efficient projects) with the principle P2 (Efficient projects should be transformed into Pareto efficient projects). The idea is to treat a more equitable distribution as a positive externality: Based on society’s valuation add an “equity” premium to a more Pareto efficient option. The author is not able to discern a simple principle for determining the size of this positive externality.

In the remainder we will ignore distributional impacts, assuming that they are duely incorporated as externalities, and focus on the economic analysis proper of projects.

In this section we have discussed the financial and the economic perspective on a project. The existence of different perspectives with potentially conflicting verdicts on a project raises the question of which perspective to take or in other words: who has standing.

The private sector decision maker focuses on financial viability and considers the economic perspective only in so far as potential government (taking the economic

\footnote{For a more technical exposition see: G. Jenkins, A. Harberger “Cost-Benefit Analysis of Investment Decisions” Chapter 14, Harvard Institute of International Development, 1996.}
perspective) changes to the economic framework vitiate financial viability, for instance abolishing subsidies or protective tariffs.

The public sector decision maker is in a different position: Normatively speaking, a necessary condition for a project to be undertaken is that it has positive net benefits from the economic perspective. Practically speaking, it is a necessary condition for a project to be undertaken that it is financially viable, as it will otherwise simply not survive to deliver the economic benefits. Positive net economic benefits and financial viability, jointly, constitute a sufficient condition for implementing a project from a public decision maker's perspective. As financial viability is achievable in the public sector by appropriating sufficient funds\(^\text{18}\), the only perspective to take from a decision making perspective is the economic perspective. If the project is economically viable, then sufficient funds should be appropriated.

Finally, a note on information: Transparency dictates that all impacts\(^\text{19}\) of the project and to which entities they accrue should be listed. The quasi infinite cost of doing so and the limited value of the information obtained through the analysis suggests a less thorough analysis.

1.3 IMPLICATIONS OF TIME

Contrary to our idealized model so far, the cashflows of a real project occur at different times. In general, a dollar at time \(t\) and a dollar at time \(t'\) with \(t \neq t'\) do not have the same value. This proposition may be justified by the reluctance of most people to trade a dollar now for a dollar one year hence. It follows that cashflows occurring at different times have to be made commensurate. In practice the cashflows occurring at different periods are expressed relative to the dollar of a given period (base period)\(^\text{20}\): Let

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\(^\text{18}\) Indeed, in a last analysis, financial viability is a function of the regulatory framework in the economy.

\(^\text{19}\) Note the following sobering truism: only impacts of the project that are valued by human beings today may be considered in the evaluation of projects. Impacts of a project on later generations, animals, etc. are thus only indirectly taken into account (or not so).

\(^\text{20}\) If the time period chosen is the presence then the net benefit thus calculated is referred to as the net present value (NPV) of an option.
t' be the period of reference and let t, t > t', be the period in which cashflow ct occurs. Let ct' be the equivalent of ct in terms of period t dollars. Let d be defined by: \( 1$ at period t = d \times 1$ at period t' \). d is referred to as the discount rate. Then, \((1+d) \times ct' = ct\) or equivalently \(ct' = \frac{ct}{1+d}\). The crucial question is how to determine the discount rate d.

For simplicity, let us consider a two period project: Investment of $100 in period 1 and operations with benefits of $110 in period 2. Then, comparing the project and the status quo option the discount rate expresses what would have been done with the $100 in the status quo option were they not invested - the opportunity cost of capital. To justify this method of estimation note that it is bad reasoning to turn down an offer by pointing out an option that is not available. It follows that the discount rate depends on the origins of the funds or, better, on what use would be displaced by the project.

Let us apply the principle to determine the correct discount rate in four examples: (1) Suppose a private investor may either give the $100 to the bank getting $108 at the end of period 2 or invest in the project. Note that the appropriate discount rate for him then is 8% and that at 8% \(NPV = 2\) and thus the project should be undertaken; (2) Suppose the government may borrow the $100 on the capital market of the economy, from which $40 come from investors willing to pay on average 12% and $60 come from savers willing to supply capital at an average of 13%. The cost of capital to the economy or discount rate then is \(0.40 \times 0.12 + 0.60 \times 0.13 = 12.6\%\). That means that put to its best alternative use the $100 would have yielded $112.60 in the economy. Adopting the project would thus destroy $2.60; (3) Suppose the government would borrow the $100 on the international capital market at 13%. Then it should not implement the project as $3 would thereby be destroyed; (4) Suppose that due to budgeting technicalities the $100 are available to the

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21 Remember: The $100 is only the medium of exchange - real resources such as land, machinery and labour are used in the project rather than in their best alternative uses.

22 That the two option two period case is a perfect representative of the multi option multi period cases is shown, respectively, in Section 1.1 and in the preceding paragraph. It is also easily seen that the sequence of benefits and costs is immaterial.

23 Note that we are here discussing the estimation of the opportunity cost of one particular input: capital (through time).
government and that it could lend the $100 in the world market at 11%. Then, the $100 should be lent as otherwise $1 is destroyed. The examples might suggest that the discount rate is necessarily positive. That this is not always the case is shown by the phenomenon that some Swiss banks charge interest on deposits.

We conclude: To retain additivity cashflows accruing at different times are expressed in a common dimension using a discount rate. The discount rate is the opportunity cost of capital.

1.4 IMPLICATIONS OF UNCERTAINTY AND RISK

Projects are events that take place in the future and, thus, the net benefits of a project is a function of future states of affairs. The effect of a given state of affairs on the net benefits of the project is usually known but it is essentially uncertain which one of a set of possible states of affairs obtains in the future. In order to rank the options, a mapping from the set of net benefits of an option under each possible states of affairs into a real number is required unless there exists an option dominating all other option in all possible states of affairs. Note that making a choice implies having chosen a subset of such maps. It is immaterial whether this is done explicitly. Transparency dictates that the choice be made consciously: An intuitively appealing map is the sum of the products of the expected probability of occurrence of a state of affairs and the net benefit of the option given that state of affairs. This is labeled the expected value of an option. Given the probabilities of occurrence of states of affairs and the net benefits given the states of affairs the riskiness of the project may be quantified, for instance in terms of variance of net benefits.

24 E. Stokey, R. Zeckhauser “A Primer for Policy Analysis” p. 175, Norton.
25 States of affairs are also referred to as contingencies.
26 That making the choice unconsciously has sufficient prevalence to merit attention is evidenced by the following result of research in managerial decision making “Although managers do not deny the possibility of failure, their idealized self-image is not a gambler but a prudent and determined agent, who is in control of both people and events”, in D. Kahneman, D. Lovallo “Timid Choices and Bold Forecasts: A Cognitive Perspective on Risk Taking”: For a further discussion on the transparency see Section 1.6.
As the probabilities assigned to the future states of affairs may have a large impact on the
design of the option and the final choice of an option much care must be taken in the
process. Recent cognitive research indicates a systematic fallacy in determining
probability distributions. Two modes of forecasting may be distinguished: An inside
view and an outside view: “An inside view forecast is generated by focussing on the case
at hand, ..., by constructing scenarios of future progress, and by extrapolating current
trends. The outside view ... essentially ignores the details of the case at hand, and involves
no attempt at detailed forecasting of the future history of the project. Instead, it focusses
on the statistics of a class of cases chosen to be similar in relevant respects to the present
one. The case at hand is also compared to other members of the class, in an attempt to
asses its position in the distribution of outcomes for the class.” Cognitive experiments
indicate, and this should not come as a surprise, that the outside view provides higher
quality forecasts while the inside view is more prevalent in forecasting.

A readily accessible example is this: “Academics are familiar with a related example:
finishing our papers almost always takes us longer than we expected. We all know this
and often say so. Why then do we continue to make the same error? Here again, the
outside view does not inform judgements of particular cases.”

The crucial issue in the applicability of the outside view is the representativeness of a
chosen class of cases. Unfortunately, there is no easy criterion to settle this issue.

Independently of the question whether we should think of our use of probabilities to
describe the future as signs of our ignorance in the face of an actually certain world or
whether probabilities are real, i.e. there are true or false probability propositions, the

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27 Source: D. Kahneman, D. Lovallo “Timid Choices and Bold Forecasts: A Cognitive Perspective on
Risk Taking” Management Science/Vol.39, No.1, January 1993 and Taylor and Brown (1988); See also:
28 Source: D. Kahneman, D. Lovallo “Timid Choices and Bold Forecasts: A Cognitive Perspective on
29 Source: D. Kahneman, D. Lovallo “Timid Choices and Bold Forecasts: A Cognitive Perspective on
30 ibidem
empirical fact remains that we can make sense of the idea that some probability
distributions are closer to the truth than others and that the process of obtaining these
more revealing probability distributions is not costless. Thus, a trade-off exists between
the costs and benefits of improving our information situation. Interpreting such an
improvement as a test, the benefits and costs may be analysed in the framework of
decision and event trees.\textsuperscript{31}

Having conducted the above analysis an option is described in two dimensions: expected
net benefits, in $, and riskiness, perhaps in variance. As above - in order to rank the
options explicitly, a mapping of net benefit and risk into one dimension has to be found.
The result is then the expected net benefit adjusted for risk.

We proceed in three steps to develop a method for adjusting for risk: (I) The risk attitude
of the reader is revealed by introspection; (II) The risk attitude of the reader is assumed to
be sufficiently representative of the risk attitude of individuals in general; (III) Implications
from (I) and (II) as to how expected net benefits ought to be adjusted for risk in the
evaluation of projects are drawn.

(I) Suppose you are offered the following two options: Option A: Throw a fair coin. If
the coin comes heads then you win $200. Otherwise you lose $100; Option B: $40 for
sure. Option A has an expected value of $50 and option B has an expected value of $40.
Which option do you choose? I expect you to have chosen option B.\textsuperscript{32} This means
nothing less than the risk involved in option B imposes a cost of that option of at least $10
in expected value terms. This is referred to as the risk premium.

Let us now slightly change the offer: You can choose a hundred times between option A
and option B. The expected value for choosing A each time (option A') is $5000 and for

\textsuperscript{31} For an exposition, see E. Stockey, R. Zeckhauser “A Primer for Policy Analysis” p.219ff., Norton.
\textsuperscript{32} If you happen to choose option A, then the line of reasoning presented here ought not be persuasive. In
this case see MacCrimmon and Wehring 1986 or Swalm 1966 for empirical studies defending that risk
aversion is prevalent in choices between favorable prospects with known probabilities. (Source: D.
Kahneman, D. Lovallo “Timid Choices and Bold Forecasts: A Cognitive Perspective on Risk Taking”
choosing B each time (option B') is $4000. I expect you to choose option A' as the risk in aggregate is minimal. The conclusion is that you are risk averse and that you are aware of the portfolio effect that diversification reduces risk. In the case of perfect diversification you are an expected value maximizer.

(II) There are two ways to derive the conclusions in (III) from (I). One is to regard your attitude and beliefs regarding risk as sufficiently representative. The other is to endow your attitudes a normative quality (not qua being your attitudes though). Either way, we then can infer the following for the evaluation of projects.

(III) From the perspective of a private project owner for whom a project constitutes a large portion of his wealth and for whom the project therefore is not part of a large portfolio a cost for risk should be added\(^{33}\) commensurate with the degree of risk-averseness. Similarly, for an individual entity exposed to high and non-diversifiable risk, consider for instance a community living next to a nuclear power station, discounting for risk is indicated.

On the other hand consider the perspective of the government in the evaluation of a given public project. We assume that government decisions should reflect individual’s valuations of costs and benefits and here, in particular individual’s valuations of risk. As the government conducts many (and let us assume statistically independent) projects in which each individual taxpayer has a small share it follows that the risk of that project is diversified away in the individual taxpayer’s portfolio and that each individual taxpayer would, therefore, want the project to be chosen on grounds of expected benefit maximization\(^ {34,35}\). In terms of options A, A’, B and B’ each project is equivalent to the

\(^{33}\) This is commonly done by increasing the discount rate as to discount for time and risk. This method, however, is conceptually unconvincing as it presumes that the riskiness of cashflows is directly positively correlated with time. A more justified approach is to ask the question for a given cashflow: What is the smallest certain payoff for which I would exchange the risky cashflow? For an elaboration on this line of reasoning see: R. Brealey, S. Myers “Principles of Corporate Finance” p. 201ff., McGraw Hill.

\(^{34}\) Note that this approach is consistent with the approach taken in the evaluation of costs and benefits from the economic perspective above (Section 1.2): Costs and benefits are computed on the basis of individual’s willingness to pay and so are here the cost of risk bearing.
government choosing for each throw of a coin whether an individual taxpayer gets the rewards of option A or option B and does so for a large number of times. As noted the individual would prefer that option A' would be chosen on his behalf rather than option B'.

An argument advanced against not discounting for risk for public investments is that it crowds out private investment in the case that the private return on a project not adjusted for risk is higher but adjusted for risk is lower than the return on the public project. This is not convincing: The extra cost due to risk is a real cost from the private perspective just like machinery or labor and thus ought to be considered accordingly. It then follows that the public project has a higher return than the private project which means that the private investor could be compensated and there would still be additional value. Thus the public project is efficient relative to the private project.

The main result in this section is that in the evaluation of a public project cashflows ought not to be discounted for risk apart from those cashflows that accrue to individuals and are not diversified away.

1.5 IMPLICATIONS OF THE PRINCIPAL-AGENT RELATIONSHIP

Adam Smith, The Wealth of Nations, 1776, Cannan Edition:

"The directors of such (joint stock) companies, however, being the managers rather of other people's money than of their own, it cannot well be expected, that they should watch over it with the same anxious vigilance with which the partners in a privated copartnery frequently watch over their own. Like the stewards of a rich man, they are apt to consider attention to small matters as not for their master's honour, and very easily give

\[3\] For a formal derivation of this result see: K. Arrow and R. Lind "Risk and Uncertainty, in Cost and Benefit Analysis" R. Layard, S. Glaister, Cost-Benefits Analysis, CUP. (The result ought to also apply to large public corporations. It does not because the managers have good reason to be risk averse.) Note that the cashflows accruing to individual entities that are not diversifiable are to be discounted for risk, as in the nuclear power case.
themselves a dispensation from having it. Negligence and profusion, therefore, must always prevail, more or less, in the management of the affairs of such a company.”

Projects are designed to optimize the objective function of the principal. That could be profit maximization in the case of a sole owner or the shareholder or welfare in the case of a government project. To implement and operate the project the principal engages agents to perform some service (either because there are too many decisions to be made or the agent has special knowledge that the principal lacks) which implies delegating decision making authority. Agents take decisions with respect to their own objective function which may or may not diverge from the principal’s objective function. An agent that acts according to the principal’s objective function is labeled a perfect agent. Then, the sum of cost accruing by aligning the agent’s with the principal’s objective function and the residual difference in value in terms of the principal’s objective function between the actions of a non-perfect agent and a perfect agent are referred to as agency cost. Note that in the absence of perfect agents, or in the absence of a 100% owner realizing the whole project, agency costs are unavoidable.

A major element in the principal-agent contract is the allocation of risk. Remember from above that risk is a function of the probabilities assigned to states of affairs and the outcomes of the project, given states of affairs, or, in this context more aptly, part of the project in given states of affairs. The two poles on a continuum of risk allocation between the principal and agent are these: The agent is remunerated independently of the actual outcome of his part of the project; The agent is remunerated dependently of the actual outcome of his part of the project. In the former case the agent bears all the risk in his part of the project. In the latter he bears no risk. In the absence of risk bearing by the agent insurance theory predicts costs due to moral hazard: The reduced incentive to

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36 This category includes monitoring cost and cost of control systems such as pay for performance.
38 In other words: In the former case there is a strong pay-performance relationship. In the latter case there is a weak pay-performance relationship.
design his part of the project in such a way as to reduce the downside were certain adverse states of affairs to occur leads to a suboptimal design of a project in expected value terms. On the other hand, if the agent is exposed to risk and is risk averse cost due to risk accrues. Thus, the principal faces an incentive - risk trade-off in the minimization of agency cost.

Clearly, and clearly independently of the type of principal, the principal-agent relationship ought to be defined in such a way as to minimize agency cost. Note that this might imply involving agents in the design process of the project.

1.6 DEFENSE AGAINST A COMMON CRITICISM OF COST-BENEFIT ANALYSIS

So far we have been describing elements of cost-benefit analysis without dealing with criticisms of the methodology. Here, we will focus on one particularly popular argument against cost-benefit analysis.

In short, in the cost-benefit analysis of an option relevant attributes are predicted and then monetized. The decision criterion, then, is: the option with highest net benefits in $ terms ought to be chosen. The argument advanced against this method, then, is of or is translatable equivalently into the following form (The number in the second column stands for the proposition in that line. The number(s) in the first column stand(s) for the proposition(s) on which the proposition in that line is based):

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39 M. Jensen writes: “While there are many events that are beyond the control of managers, there are very few events whose consequences are beyond managers control (in Course Notes, CCMO, 1995); Levitt et al. (1980): “A balancing of the risk should be sought between the owner and his contractor or designer in order to utilize the incentive value of bearing risk while minimizing a contingency charged for accepting the risk”; C. Gordon (1994) seems to confuse the occurrence of different states of affairs (uncontrollable) with the effects of a given states of affairs on the project (controllable - a question of the design of the project) when he writes: “A company’s efficiency in handling risk is based on its power to control the risk. ...”.

30
Either the attributes of the different options are too difficult to predict or there exists at least one attribute that is not monetizable or both.

The description of an option in $ terms does not contain all that is needed to make a decision. The decision criterion is not valid.

Indeed, supporters of this view have no shortage of examples to justify their premiss. Here just one example: How should Turkey predict and monetize the political implications of building a water dam enabling them to considerably reduce Syria’s water supply?

Our defense of cost-benefit analysis is not going to be to claim that predicting and monetizing, even choosing the right, attributes is an easy matter. This is a losing proposition. Our argument is this:

There exists no option such that it is better than all other options with respect to all attributes, i.e. no dominant option;

In choosing an option a relative valuation (trade-off) is implied between at least two attributes (potentially many). This choice then reveals that the decision maker believes in one of the set of monetizations of these attributes that are consistent with his choice. Thus a set of monetizations is necessarily implied in a choice;

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40 I realize that this style of presentation is pretentious in that it resembles the form in which logical or mathematical arguments are presented. It does not need mentioning that the conclusiveness of my argument is not that of a mathematical or logical proof. I believe that the benefits due to a more lucid presentation outweigh the cost due to pretentiousness (without monetizing).

41 Any index would do: An index is a map from an n-tuple into a 1-tuple. The index of choice, clearly, is to map into money.
The choice is derived more transparently if the decision maker explicitly states his valuation of attributes, i.e. monetizes the attributes: Disagreement on which option to choose is transferred to disagreement on how to value certain attributes. This type of disagreement tends to be more amenable to a principled solution as participating parties are less emotional about abstract issues: Settling in abstract how the attribute should be valued and then accept the implications for the decision at hand.  

Transparency is a virtue; 

What is virtuous ought to be done; 

Attributes ought to be monetized.  

The crux of the matter is this: Even though monetizing and predicting attributes is subject to error and often unpleasant we do so implicitly by choosing an option anyway. It seems preferable to explicitly predict and monetize in a principled way the attributes as good as

\[\text{42 The effectiveness of this approach of settling conflicts is somewhat reduced by a mode of argument referred to as reductio ad absurdum: If A implies B and B is false then A is false: If the principle implies that option A is better than option B, and I know that option B is better than option A then the principle, whatever reasoning we added in its favour, is false. While a valid and very powerful mode of reasoning, its application in this context seems to be a sign of intellectual dishonesty.} \]

\[\text{43 The argument for "difficult" to predict attributes is analogous. Line 6, then, reads: Attributes ought to be predicted.} \]

\[\text{44 Should$4 million be spent on new road signs which are expected to save one life? What about$10,}$20 or$100 million? (We assume for the purpose of illustration that reducing fatal road accidents is the only benefit of new road signs). Consider the thesis that the value of life is infinite: An individual is thinking about crossing a street in order to reach a bakery and believes that the value of life is infinite. In expected value terms there is some finite benefit of crossing the street, namely being able to go shopping in the bakery. Note, however, that there is an infinite cost of doing so as the product of the a small probability of having a fatal accident and the infinite negative value of death is infinite. Thus, such an individual would never cross the street to go shopping in the bakery or for that reason do anything which increases the probability of untimely death. It turns out that there are no individuals behaving in such a way and that therefore the value of life, or better the value of statistical life, is not perceived to be infinite. For different approaches of determining the value of life by revealed preference see: M. Jones-Lee "Safety and the savings of life: The economics of safety and physical risk" Cost-Benefit Analysis, ed. R. Layard, S. Glaister, CUP.} \]
we can, than to take “gut” decisions. Note that in the face of less than perfect predictions and monetizations a diligent sensitivity analysis is indicated.

Two remarks on the above argument: Assumption 1 is in place as the decision problem otherwise has a trivial solution. The argument simplifies considerably and perhaps gains in force if one considers the following special case where all but one attribute, call it X, is monetized and there are two options A and B. Option A lacks the attribute altogether but, based on the other attributes, has $n more benefits than Option B. Choosing option B than implies that the non-monetized attribute is valued at at least $n.

1.7 SUMMARY

In Chapter 1 we have discussed the properties of projects in a very general way. We defined a project as an entity having the following properties: It consumes inputs and produces outputs through time and affects entities and collections of entities in the process. We then elaborated consequences from these properties. These findings are applicable to everything in the real world that fits the definition of a project or in other words that have the above properties. As there are many such things our findings are generally applicable. Unfortunately, there is only so much that can be said on projects without making further assumptions on the kind of goods used and consumed or the distribution of cashflows through time. In order to be able to deliver practical and specific evaluation criteria it is necessary to make additional assumptions thus restricting our attention to a subset of the category of projects. This is the objective of Chapter 2. The subcategory of projects considered comprises many, if not all, large-scale transportation infrastructure projects.
CHAPTER 2: FOCUSSING ON A SUBSET OF PROJECTS: LARGE-SCALE INFRASTRUCTURE PROJECTS

2.1 DEFINING A SUBSET: LARGE SCALE TRANSPORTATION INFRASTRUCTURE PROJECTS

We focus our attention to a subset of projects. It is to those projects that, in addition to the properties stated in Chapter 1, also have the following properties:

1. Characteristics of supply are only alterable in large steps - we refer to this as lumpiness in investment;

2. Real investment cost are constant with respect to time;

3. Demand is monotonically increasing with respect to time;

4. Demand is non-uniformly distributed throughout the day and the year - we refer to this as peaking in demand;

5. Natural monopoly: fixed costs of providing good are high relative to the variable cost so that average cost declines over the relevant range of demand\(^45\).

The extension of this subset of projects includes (many) large-scale transportation infrastructure projects: (1) Investment in transportation infrastructure is lumpy and large: a partial bridge, tunnel or locomotive are without value; (2) This is a plausible simplifying assumption; (3) The benefits as measured by the demanders willingness to pay for transportation generally increase through time as demand for transportation is positively related with economic activity and economic activity tends to increase through time; (4)

Demand for transportation is non-uniformly distributed through time; (5) Transportation infrastructure such as tunnels or bridges is characterized by large investment cost and low marginal cost over the range of demand up to capacity. Thus, they satisfy the definition of a natural monopoly which means that such a good is provided most efficiently by a single supplier - why have two bridges if one would be enough.

As evaluation of transportation projects is clearly worthwhile, it is warranted to consider the subset of projects defined by assumptions 1 - 5. For convenience we refer to the subset as transportation projects. Note, however, that this does not imply that all and only that which is commonly referred to as a transportation project falls into this category.

Let us now consider the typical situation in the evaluation of a transportation project from the financial and economic perspective. To simplify terminology and without loss of generality, let us refer to the good produced in the status quo or in a proposed project as a transit and the entity that enables the transits the transportation link. For the same reason, terms specifically used in the evaluation of transportation systems are used. The question we want to answer is how to optimally deliver the transportation link. The options available differ with respect to technology, timing of implementation and ownership of transportation link.

2.2 NATURAL MONOPOLY, OWNERSHIP AND PRICING

From the economic perspective the efficient price, \( P^* \), for a unit of a good is determined by the intersection of the consumers willingness to pay curve (demand curve) and the marginal cost curve: Assume that the price \( P \) was higher than \( P^* \). Then a potential consumer valuing this unit of the good lower than \( P \) but higher than \( P^* \) does not consume. The difference between the consumer's valuation and the cost of that unit is then welfare foregone. Assume that the price \( P \) was lower than \( P^* \). Then a potential consumer valuing this unit of the good lower than \( P^* \) but higher than the price does consume. The difference between the consumer's valuation and the cost of that unit is then welfare foregone.
In order to focus on one issue at a time, we assume that no externalities and distortions are present in the market for transits, i.e. marginal cost = marginal social cost. Dropping this assumption is expected to increase the difference in net benefits between optimizing a project from the financial perspective versus optimizing a project from the economic perspective. To begin with, we assume that no congestion occurs on the link.

As in a natural monopoly the fixed costs are high relative to the variable costs and the marginal cost is below average cost. Thus, charging the economically efficient price results in the project operating at a financial loss. On the other side, optimizing the project in financial terms by charging the price where the marginal revenue curve intersects with the marginal cost curve implies welfare losses. Note that providing a project privately implies that it is optimized financially. Providing it publically is expected to lead to economic optimization. Making users pay their way by charging average cost is suboptimal relative to both the economic and the financial perspective. The situation is depicted diagrammatically in Figure 2.2-1.

In times of congestion the marginal cost curve is not constant as depicted in the diagram. This is illustrated by the following example: Suppose 999 vehicles using a bridge require 10 minutes each to cross. Suppose the 1000th vehicle has the effect of increasing the travel time for each vehicle by 1 minute. The marginal cost of the 1000th vehicle is then 1010 minutes. Optimally, this vehicle would then be charged the monetary equivalent of 1010 minutes for the transit. The occurrence of congestion is explained by the lumpiness in investment and the peaking in demand: The trade-off is between having more capital cost and less cost due to congestion and having more cost due to congestion but less capital cost.

The effect of congestion on pricing is depicted diagrammatically Figure 2.2-2.

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46 Note that the private and public provision are two poles of a continuum. The evaluation and design of joint public and private provision follows from the properties of these absolute cases.
48 This example is plagiarized from: D. Weimar, A. Vining “Policy Analysis” p.48, Prentice Hall.
FIGURE 2.2-1: SOCIAL SURPLUS LOSS FROM NATURAL MONOPOLY

- **MC**: marginal cost
- **MR**: marginal revenue
- **AC**: average cost

Net social surplus loss of monopoly pricing relative to efficient pricing: abc
Net social surplus loss of average cost pricing relative to efficient pricing: acf

FIGURE 2.2-2: PRICING IN THE PRESENCE OF CONGESTION

Excludable Nonrivalrous Goods (a) Social Surplus Loss with Positive Price in the Absence of Congestion (b) Appropriate Positive Price in the Presence of Congestion
In the face of an upward sloping marginal cost curve, then, the following situation, depicted in Figure 2.2-3\textsuperscript{50} might arise.

Note that, contrary to the case of the flat marginal cost curve considered above, charging the economically efficient price $P_c$ yields a financially viable project (i.e. total financial benefits $> $ total financial costs). Also, contrary to above, making the users pay by charging average cost leads to transits being valued at less than their cost (overconsumption) and thus to an inefficient allocation. As above, optimizing the project financially yields an undersupply from the economic perspective. In an investment decision this translates into a too small capacity and in the pricing decision this translates into a too high price from the economic perspective\textsuperscript{51}. A drastic real life example for inefficient pricing (though not for a “too small investment”) is the (private) Acapulco - Mexico City toll road in 1992: The private toll road costing more than USD 100 from Acapulco to Mexico City is virtually empty while the parallel non-toll road is congested\textsuperscript{52}.

In the face of the inefficiency of optimizing a transportation project financially, the current popularity of private transportation infrastructure projects might come as a surprise\textsuperscript{53}. Before we turn to arguments in favor of private sector supply let us investigate tools to mitigate the efficiency gap between optimizing a transportation project financially and economically. Classically two regulatory tools are used: taxation and price ceilings.

Taxation has the effect of redistributing part of the monopolists rent to the general public. However, the quantity supplied is further reduced and the price charged is higher than in the non-taxation situation. The price increase may even be higher than the (per unit) tax.

\textsuperscript{50} Source: D. Weimar, A. Vining “Policy Analysis” p. 38, Prentice Hall.
\textsuperscript{51} This result holds irrespectively of the existence of congestion or not.
\textsuperscript{52} Source: Author’s experience.
\textsuperscript{53} We assume that a private supplier of transportation infrastructure optimizes with respect to the financial perspective as opposed to a public supplier who optimizes with respect to the economic perspective.
From an efficiency perspective deadweight loss\footnote{Deadweight loss is a reduction in the sum of consumer's surplus and producer's surplus. Consumer's surplus is the amount of money consumers are willing to pay in addition to what they actually pay. Producer's surplus is the amount of money producers receive in addition to what they would be willing to produce for. See Figure 2.2-5.} is incurred in the process of taxation. This result is derived in Figure 2.2-4\footnote{Source: Pindyck, Rubinfeld “Microeconomics” p.329, Prentice Hall.}.

A price ceiling has a similar effect as taxation: The quantity supplied is reduced\footnote{As marginal cost to the provider is small (marginal cost increase in congestion is mainly due to cost of time of consumers) this effect may be small as a consequence of operations choices. But price ceilings, clearly, lead to underinvestment.}\footnote{Source: R. Pindyck, D. Rubinfeld “Microeconomics” p. 279, Prentice Hall.}. The allocation process might disparagingly be described as Soviet style through queues: An effective way to accumulate economic cost due to the value of time. Furthermore, deadweight loss is incurred. In the case of sufficiently inelastic demand the consumer surplus might even be reduced. These results are derived in Figure 2.2-5\footnote{J. Miller “Aligning Infrastructure Development Strategy to Meet Current Public Needs” Doctoral Thesis.}.

In the light of the above results, the findings in Miller (1995)\footnote{Definition: One business entity that performs design, construction, construction and long-term financing, and temporary operation of the project. At the end of the operation period, which can be many years, operation of the project is transferred to the owner; Source: Gordon “Choosing Appropriate Construction Contracting Method” Journal of Construction Engineering and Management, Vol. 120, No. 1, Mar. 1994, p.196.} concerning a privately provided (Build-Operate-Transfer\footnote{Definition: One business entity that performs design, construction, construction and long-term financing, and temporary operation of the project. At the end of the operation period, which can be many years, operation of the project is transferred to the owner; Source: Gordon “Choosing Appropriate Construction Contracting Method” Journal of Construction Engineering and Management, Vol. 120, No. 1, Mar. 1994, p.196.}) tunnel in Hong Kong should not come as a surprise:

"The traffic projection risk turned out not to exist. Traffic volumes have been at capacity through much of the franchise period, despite surcharges by the government to the tolls charged by the franchisee. Because the financial performance of the tunnel is private, the actual rate of return ("ROR" (sic!)) on this investment are (sic!) not known, but it is reasonably certain that ROR exceeds 15-18%, since traffic volume remains steady at tunnel capacity."
FIGURE 2.2-3: PRICING IN THE PRESENCE OF UPWARD SLOPING MARGINAL COST CURVE IN MONOPOLY

FIGURE 2.2-4: EFFECT OF TAX ON MONOPOLIST

FIGURE 10.5 Effect of Excise Tax on Monopolist. With a tax \( t \) per unit, the firm's effective marginal cost is increased by the amount \( t \) to \( MC + t \). In this example, the increase in price \( \Delta P \) is larger than the tax \( t \).
FIGURE 2.2-5: EFFECT OF PRICE CONTROLS

The price of a good has been regulated to be no higher than \( P_{\text{max}} \), which is below the market-clearing price \( P_0 \). The gain to consumers is the difference between rectangle \( A \) and triangle \( B \). The loss to producers is the sum of rectangle \( A \) and triangle \( C \). Triangles \( B \) and \( C \) together measure the deadweight loss from price controls.

**FIGURE 9.2** Change in Consumer and Producer Surplus from Price Controls. The price of a good has been regulated to be no higher than \( P_{\text{max}} \), which is below the market-clearing price \( P_0 \). The gain to consumers is the difference between rectangle \( A \) and triangle \( B \). The loss to producers is the sum of rectangle \( A \) and triangle \( C \). Triangles \( B \) and \( C \) together measure the deadweight loss from price controls.
Is the conventional wisdom in Hong Kong that "if the private sector will provide them, it is substantially better for the public and for the government to have private entities design, build, operate and maintain major infrastructure facilities"\(^{60}\), ungrounded?

A possible rationalization is provided by agency costs: As the link between pay and performance and the monitoring of the actions by the taxpayer of public decision makers tend to be weaker than in the private case the agency costs are to be expected to be higher. One effect of this fact is described as the private provision yielding a "sanity check" on the worthwhileness of the project. Another effect is described as the private sector being "more efficient"\(^{61}\). Note that these positive effects have to be weighed against the cost due to risk\(^{62}\).

Another argument in favour of private provision is that governments often do not have enough money to provide all infrastructure "needs". Note, firstly, the misleading description of the situation by the use of term "needs"\(^{63}\): There are no needs in the absolute sense from the economic perspective - only a weighing of benefits and costs. This appeal to budget constraints, then, rests on the assumption that governments do not

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\(^{61}\) A privately designed and built road and bridge in Hong Kong had capital cost averaging 60\% of government estimates; Source: J. Miller "Aligning Infrastructure Development Strategy To Meet Current Public Needs" Doctoral Thesis, pp. 47, 49.

\(^{62}\) For an estimate of the cost of risk consider: J. Miller "Aligning Infrastructure Development To Meet Current Public Needs" Doctoral Thesis, pp 41, 42: "What makes large infrastructure projects suitable for private financing, from the point of view of financial markets? ... Third, there must be a "good" return available from the project ... at levels higher than other, more traditional investments. (Returns of 15-18\% are typical for these projects in Hong Kong)."

\(^{63}\) M. Jensen "The Nature of Man": "Using the word need as an imperative is semantic trickery. The media and press are filled with talk about housing needs, education needs, food needs, energy needs, and so on. Politicians and others who use that language understand that the word need carries emotional impact. It implies a requirement at any cost; if the need is not met, some unspecified disaster will take place. Such assertions have a far different impact if restated to reflect the facts. The proposition that "people want more housing if they can get it cheaply enough" does not ring out from the podium or over the airwaves with the same emotional appeal as "people need more housing"."

\(^{64}\) Consider the following publications: European Conference of Ministers of Transport "European transport trends and infrastructural needs" (1995); J. Miller "Aligning Infrastructure Development To Meet Current Public Needs" Doctoral Thesis.
have the ability to raise funds through debt or taxes, even though the returns of the project are higher than the cost of capital. And this assumption is rarely met.65

In a similar vein, consider this argument by Miller: A significant additional benefit is that these landfills were financed in private markets by the operators themselves. If, what is likely, the private operators are regarded as more risky than the government, then private financing is a cost and not a benefit.

We note that the decision to provide transportation infrastructure privately or publically is by no means settled by appeal to catchwords such as “the private sector is more efficient”. The benefits of private sector provision, such as higher “efficiency”, sanity check and less agency costs (from the financial perspective), have to be weighed carefully against the costs (from the economic perspective), such as agency costs accrued by optimizing a project from the financial rather than the economic perspective and risk. This cost-benefit analysis is applicable to any combination of public and private supply, the so called public-private partnerships. In fact, the procurement system ought to be considered as just another variable, analogous to technology, of the project which should be chosen such as to optimize the overall project economically.

Let us, finally, turn to one particular alternative to monopoly pricing and efficient pricing: The policy of average cost pricing.

In order to implement average cost pricing the project has to be either public or private with the proviso that instruments are available to the government to insure that the private supplier does not revert to monopoly pricing. The latter proviso is not easily satisfied.

As derived in Figure 2.2-1, average cost pricing is inefficient. The question, then, arises whether there are benefits outweighing the efficiency loss. It is often held that average

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65 The reply that governments might not choose to take debt even though the project has positive net benefits hardly carries normative weight.

cost pricing is less arbitrary than efficient pricing. On closer inspection, however, this position is as reasonable as to believe that strawberries should cost the same throughout the year, i.e. not reasonable at all. Another line of argument appeals to justice. Average cost pricing is claimed to be more just than efficient pricing as the users pay their way. We will not pursue the question of justice.

From the above discussion we can safely, and rather modestly, conclude a necessary condition for a project to be a candidate for implementation: Efficiently priced, a project has positive net benefits from the economic perspective.

2.3 TECHNOLOGY AND TIMING

We begin by developing a method for deciding in a given year whether to alter supply radically\(^{67}\) or whether to continue with the status quo, i.e. we assume that there are only two options. Let us refer to the former as the investment option and to the latter as the status quo option. Subsequently we discuss limitations of the method and propose ways to overcome them.

The relevant technological attributes on a per year basis of an option may be analysed into its fixed cost and variable cost structure.

Fixed costs accrue independently of the quantity of transits. Fixed costs comprise the costs incurred to attain a capacity and a variable cost structure. In other words, fixed costs comprise the cost of capital. As maintenance in this framework is such that it retains the cost structure, depreciation is not considered. In addition fixed costs comprise the cost of externalities that accrue independently of the quantity of transits, for instance a neighbourhood that is bisected by a road.

Variable costs are a function of the quantity of transits. Examples of variable costs are energy costs, maintenance, time spent travelling and safety costs (being exposed to a

\(^{67}\) See assumption 1, Section 2.1.
certain probability of an accident). Furthermore, and importantly, at capacity the cost of a marginal transit is large due to congestion and the rate of increase of variable costs thus increases. As variable costs of n transits is defined to be the sum of variable costs of n - 1 transits plus the marginal cost of the nth transits the property concerning congestion of a given option is reflected in the variable cost structure. In addition, variable costs comprise externalities that are a function of quantities of transits, as pollution for instance, or safety.

We assume that the investment option has higher fixed costs and lower variable costs (and, hence, lower marginal cost) over the relevant demand range than the status quo option. This assumption does not imply much of a loss of generality: If the investment option has higher fixed costs and higher variable costs then do not invest; The investment option is unlikely to have lower fixed costs as the status quo option as the latter does not bear capital costs (=sunk cost) as compared to the investment option.

Now, suppose investing could be done in an instant and the demand curve for the year ahead was known. Suppose that, as discussed in Section 2.2, both options would be operated by charging the efficient price. We may then calculate net benefits for each option for that year by subtracting total costs from total benefits.

If net benefits of the status quo option is larger than that of the investment option then do not invest for the difference in value would otherwise be destroyed. In this case decision making is deferred by one year in which, then, the analysis ought to be conducted again.

If net benefits of the investment option is larger than that of the status quo option then invest for not only is value created for that year but for the years thereafter as a consequence of the assumption that demand is monotonically increasing with respect to time. The reasoning is this: (1) As demand is monotonically increasing with respect to time the number of transits in both, the status quo option and the investment option, is going to increase for the consequent years. (2) Each additional transit yields the same

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68 See Section 2.2.
69 See assumption 3, Section 2.1.
gross benefits (as measured by the consumer’s willingness to pay curve) to both options but costs less in the investment option than in the status quo option as the investment option has lower marginal costs than the status quo option. It follows (3) that each additional transit yields larger net benefits to the investment option than the status quo option. On the basis of (1) and (3) we can, then, deduce that net benefits of the investment option are larger than net benefits of the status quo option for the years thereafter and that the difference is growing with respect to time. Q.E.D.

Conversely, given the technology of both options and assuming the shape of the demand curves to be constant, a critical demand curve can be determined for which the investment option is superior. At a given point in time the actual demand curve could then be compared to the critical demand curve. Based on projections of demand, a year could be determined when investment should take place. Dropping the assumption about demand curves having the same shape necessitates talk about a set of critical demand curves but does not change the approach substantially. The reasoning is graphically depicted in Figure 2.3.

The situation is slightly more complicated (and realistic) if we drop the assumption of instant investment. Suppose that the investment period is t years and there is no use before year t. We would decide to invest now based on the projection of the demand schedule t years hence whether net benefits of the investment option are larger than those of the status quo option, then. Conversely, given a set of critical demand schedules and projections of demand schedules we could determine now in which year it is optimal to invest: t years before the net benefit of the investment option is larger than the net benefit of the status quo option.

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70 The seed idea for this approach is to be found in: A. Harberger “Cost-Benefit Analysis of Transportation Projects” Project Evaluation, University of Chicago Press.  
71 Source: G. Jenkins, A. Harberger “Cost-Benefit Analysis of Investment Decisions” Harvard Institute for International Development, Chapter 5, Figure 5-4.
FIGURE 2.3: TIMING OF PROJECTS

WHEN POTENTIAL BENEFITS ARE
A CONTINUOUSLY RISING FUNCTION OF CALENDAR TIME
BUT ARE INDEPENDENT OF TIME OF STARTING PROJECT

Benefits and Costs

\[ B(t) \]

\[ rK \]

\[ t_1, t_2 \]

\[ t \]

47
This decision principle is, then, described by the following algorithm (Suppose we are in year k and we want to decide between starting construction to implement the investment option, which takes t years, or not do so):

1. Forecast demand for the year $k + t$ (in order to determine benefits);

2. Forecast the cost situation for operating in the investment option and for operating in the status quo option in the year $k + t$;

3. Calculate expected net benefits for each option in the year $k + t$ by subtracting total costs from total benefits for that year;

4. Choose option with larger net benefits: If operating in the investment option is expected to yield larger net benefits in year $k + t$ then start construction now; If operating in the status quo option is expected to yield larger net benefits in year $k + t$ then do not start construction now and conduct the same analysis in year $k + 1$ for year $k + t + 1$ (i.e. defer decision making for one year); In the latter case we operate in the status quo option in the year $k + t$.

This method has two major advantages over the traditional method of setting up a cashflow table to model the whole life of the project:

Firstly, the forecasting requirements are considerably less. In the traditional method the states of affairs have to be predicted for the whole life of the project, which often means making predictions for more than 30 years into the future. Such long term predictions are unconvincing. In our method, on the other hand, we only need to predict the states of affairs t years (the number of years it takes to implement the investment option) into the future to choose between starting construction now or deferring the decision by a year. As $t$ is always less than the life of the project and forecasts are, generally, more reasonable the
sooner the states of affairs forecasted, our decision method is based on higher quality forecasts and, hence, yields higher quality decisions.

Secondly, our method ensures optimal timing of investment. Due to the lumpiness of investment in transportation projects the timing of investment is not trivial. If the investment is done too early then (conceptual implication), in the beginning of the project, the benefits accrued due to lower variable costs and additional transits are outweighed by the cost of capital. Conversely, if the investment is done too late, then the benefits foregone by higher variable cost and reduced transits (in the status quo option relative to the investment option) outweigh the cost of capital. Thus, a cashflow table for a proposed investment that indicates a positive NPV, is consistent with a suboptimal project relative to timing. Our method, on the other hand, as it is conducted on a year by year basis, ensures optimal timing: Start operation in the year in which net benefits of the investment option is larger than in the status quo option.

The simple decision procedure outlined above critically rests on the assumption that there is only one investment option. While investment options are, ex hypothesi, lumpy, there generally are different options with respect to technology available. In fact, there is a tendency in the design of options to uncritically accept technological constraints and, thus, to choose suboptimal technology. It is our goal now to extend the above decision criterion to choosing among disparate technology choices, and in the same process facilitate the design process of options.

Note firstly that the question of which investment option to choose arises only if in the given year at least one investment option is more efficient than the status quo option. Otherwise no judgement is required. This point is very important, practically, for being able to wait invariably improves the information situation and the technological options available. Thus, unless at least one investment choice is more efficient than the status quo option, defer decision making.
We begin with special cases. Suppose at least one investment option to be more efficient in year n and all investment options to have the same capacity, or more precisely, the same cost structure at capacity and the investment to extend the capacity thereafter is expected not to be affected critically by which investment option is chosen. The investment options differ with respect to their cost structure up to capacity. Then we compare different investment options in the following way: Based on projections of demand schedules (from the year in which at least one investment option dominates the status quo option) we determine the net present value for each technology option implemented at optimal time and operated economically optimal. In this case a cashflow table has to be set up for the relevant time period in which the cashflows are listed as they accrue. Note that the residual value of the project at the end of its life is assumed to be the same for each option at the moment.

Then, the decision criterion is: Choose option that maximizes net present value. Unfortunately, rather more extensive demand projections are required in the comparison between investment options than in the comparison between the status quo option and an investment option. A trivial case, probably not without application though, is that one option dominates all others over the demand range considered. Then, the decision criterion is: Choose the dominant option.

Let us drop the assumption that the costs/benefits of the extension of the investment option is not affected by the choice of option. The consequences of doing so are mitigated as the costs and benefits tend to accrue far into the future and, thus, discounted for time, have a relatively small impact in present value terms. Also, the technological options at that point in time in the future are likely to be different due to progress. Nevertheless, properly adjusted, these effects of the options should be taken into consideration.

Let us now drop the assumption of all investment options having similar capacities. Often there is the choice between making one large investment or investing in stages (though still lumpy), with the former having a higher capacity than the latter. In this case we cannot
compare the net present values by discounting net cashflows until demand reaches capacity as different demand ranges, or more commonly put, different quantites of periods of time, are covered by the respective options. We want to achieve comparability between such options. The solution is to create compound options with similar capacity. Then, as above (from the demand schedule onwards in which at least one investment option dominates the status quo option) we calculate the net present value based on demand projections.

Note, however, two difficult to quantify advantages of a composite option compared to a non-composite option. Firstly, the number of technological options increase through time and, secondly, the demand information improves. As the time periods considered are long, these are substantial advantages. It is often argued against a composite option that the overall cost is higher than that of the single option. While this might be the case, much care must be taken to discount cost properly for time. Also, one would want to consider only real and not nominal cost increases. Though painfully obvious, to make this point is warranted due to the popularity of disregarding it.

2.4 SUMMARY OF PART I

In Part I we have discussed the design and evaluation of projects in general and transportation projects in particular.

We began in Chapter 1 by defining the concept of a project. The difference between the economic and financial perspective on projects was discussed. The prevalent method for comparing cashflows at different times, the net present value rule, was described and defended. The prevalent treatment of risk was described. A not so prevalent finding was that from a government’s perspective the riskiness of outcomes of a given project does not constitute a cost in the case that the project, in a certain sense, is only a small part of the overall portfolio of projects in the economy. This finding will be used extensively in Part

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72 This condition might not be satisfied for large projects in small economies. We will discuss this issue for the tunnel project in Argentina in Part II.
II. We then went on to consider implications of organization theory for the design of projects. We used the concepts of principal and agent to investigate methods for minimizing costs due to different objective functions of entities involved in a project. Finally, we defended cost-benefits analysis against the criticisms that outcomes are impossible to predict and monetize by pointing out that, in a precise sense, this is done inevitably by taking a decision.

In Chapter 2 we derived design and evaluation implications from the salient properties of transportation infrastructure projects. Using microeconomic theory we investigated the difference in outcomes if such infrastructure is provided privately, i.e. optimized relative to the financial perspective, or publically, i.e. optimized relative to the economic perspective. We found there to be sizable potential for agency costs if such infrastructure is provided privately. We listed benefits as well as other costs of private provision. We used the findings to question the current trend of private transportation infrastructure provision. We found that the judicious choice between public or private (or a hybrid version of the two) provision requires a careful cost-benefits analysis. These findings are of no practical importance to the analysis conducted in Part II. However, at a more advanced stage in the formulation of the project they are certainly applicable and should receive due consideration.

Of much practical importance, on the other hand, is the finding that it is a necessary condition for a project to be implemented that it has positive net benefits in economic terms if prized efficiently.

Finally, we derived concrete decision criteria with respect to technology and timing of projects. We described and elaborated on a method that allows under certain and prevalent conditions that only the states of affairs of the year at the start of operations of the project need to be forecasted rather than the states of affairs for the whole life of the project in order to choose the timing of an investment. This greatly reduces the forecasting requirements and insures optimal timing as compared to the more traditional method of
setting up a cash-flow table for the life of the project. As forecasting time periods of more than, say, ten years is unconvincing this is a major advantage over the traditional method.

We developed the idea of comparing technological options over demand ranges rather than on the basis of demand projections as in the traditional method of cash flow tables. To my knowledge this method is new. The advantage is that in the case of an option being dominant over the relevant demand range no long term demand forecasts are required to make a decision, which constitutes a considerable shortcut. The last two methods are applied in Part II, where we investigate the economic feasibility of a tunnel project.
PART II: APPLYING THE FRAMEWORK: THE MENDOZA - LOS ANDES TRANSPORTATION CORRIDOR PROJECT
CHAPTER 3: INTRODUCTION TO THE MENDOZA-LOS ANDES TRANSPORTATION CORRIDOR PROJECT

In the remainder we are going to apply the framework developed in Part I. We conduct a cost-benefit analysis from the economic perspective of a particular transportation infrastructure project: It has been proposed to substantially upgrade the transportation link between Mendoza (Argentina) and Los Andes (Chile) by complementing a winding and avalanche-afflicted mountain route by a tunnel at lower altitude.

The flow chart in Figure 3-1 depicts the logical structure of Part II. The flow chart serves as an overview and as a reference guide.

The Mendoza - Los Andes corridor is located in the region of 70 degrees west and 32 degrees south. The terrain is of markedly alpine character - the existing road is located in the area of the Aconcagua, at an altitude of almost 7000m the highest mountain in South America, and crosses a mountain pass with an altitude of 3185m. The extreme climate has caused the corridor to be closed on average 30 days per year during the winter months. The options to be discussed are intended to alleviate this problem by using a tunnel at an altitude of approximately 2600m.

The Mendoza - Los Andes corridor serves as a connection between Argentina and Chile and, indirectly, between Chile and Uruguay, Paraguay and Brazil.

The geographic situation is depicted in Figure 3-2.

A sectional drawing of the corridor is displayed in Figure 3-3 (E.F.DP.190/191)

73 The economic perspective, then, is from the economy comprising the Chilean and the Argentine economy.
Chapter 3
- Background information
- Introduction to model

Chapter 4
- Description of technological options
- Determination of cost structure

For each technological option, determine marginal cost and total cost as a function of quantity of transits:
\[ mc = f(q); \quad tc = g(q) \]

Chapter 5

Benefit methodology:
- determining gross benefits as a function of demand curve and quantity of transits:
\[ gb = k(d,q) \]

Demand information
- shape of demand curve
- predicting future demand for 5 scenarios:
\[ demand = h(time) \]

Chapter 6
Calculating net benefits as a function of demand curve (For each technological option):
1) Equalize marginal cost and demand to obtain the quantity of transits, \( p \), for that demand:
\[ p = j(d) \]
2) Calculate gross benefits: \( gb = k(d,p) \)
3) Calculate total cost: \( tc = g(p) \)
4) Net benefits is gross benefits - total costs: \( nb(d) \)

Then: Determine optimal technological option over range of demand

Timing of investment option
1) Determine optimal timing for investment for the five demand scenarios;
2) Analyze stochastic demand forecast using the Monte-Carlo method;
3) Sensitivity analysis.

Chapter 7
Discussion of results and recommendations
FIGURE 3-2: MAPS OF MENDOZA-LOS ANDES TRANSPORTATION CORRIDOR

Pacific Ocean

Los Andes

Mendoza

Asuncion

Sao Paulo

Rio de Janeiro

Santiago

Montevideo

Buenos Aires

Bi-Oceanic Corridor
SECTIONAL DRAWING OF MENDOZA-LOS ANDES TRANSPORTATION CORRIDOR

FIGURE 3-3: SECTIONAL DRAWING OF MENDOZA-LOS ANDES TRANSPORTATION CORRIDOR

PERFIL ESQUEMATICO
MENDOZA-CRISTO REDENTOR
Km 0.00 - Km 198.48

PERFIL ESQUEMATICO
LOS ANDES - CRISTO REDENTOR
Km 0.00 - 65.245
Argentina has a population of about 33 million with 40% living in the capital Buenos Aires. Argentina had a gross domestic product (GDP) in 1990 of $26 billion\textsuperscript{74} resulting in a per capita GDP of $787 (this figure seems rather low). The centers of economic activity are congruent with the centers of population, with the main center being in Buenos Aires. The outlook for the growth of the Argentinian economy is promising: Prudent monetary policy and a market based approach for the allocation of resources are being implemented.

The population of Chile in 1991 was 13.4 million. The main population centre is the capital, Santiago de Chile, and the adjacent port, Valparaiso. The distribution of the populations of Argentina and Chile is depicted in Figure 3-4 (E.F.D.73).

Chile had a GDP in 1993 of $41.7 billion (in 1988 $s), resulting in a per capita GDP of $3111. The centers of economic activity are congruent with the centers of population, with the main center being the Santiago de Chile/Valparaiso Area. Chile has a longer history than Argentina of keeping inflation down and limit distortions in the markets. For the same reason its’ outlook on economic growth are promising.

Following a period of military conflict between Argentina and Chile ending in 1984, trade between the two countries has been rapidly increasing - though, admittedly, from a modest base of $195 million in 1985. Trade between Chile and Brasil, Paraguay and Uruguay follows a similar pattern. A histogram of trade between Chile and Argentina, and Chile and Brasil, Paraguay and Uruguay is depicted in Figure 3-5\textsuperscript{75}. As Chile joined Mercosur in 1996 barriers to trade will be reduced.

Growing economies and the liberalization of trade will result in an increase of trade. This translates into an increase in demand for transportation in the area. Tourism, as it is positively correlated with economic activity, is to be expected to contribute to this trend. The transportation infrastructure currently in place is not designed to exploit the trade

\textsuperscript{74} World Bank “From Insolvency to Growth” International Bank for Reconstruction and Development, 1993.

\textsuperscript{75} Source of the data used: E.F.D.147/149/150/163
FIGURE 3-4: POPULATION DISTRIBUTION IN ARGENTINA AND CHILE

REPUBLICA CHILE

REPUBLICA ARGENTINA
DIVISION POLITICOS TERRITORIAL
FIGURE 3-5: TRADE BETWEEN CHILE AND MERCOSUR 1974-1994

Chile - Argentina
- Chile - Br./Par./Ur. (since 1991)
- total (since 1991)
potential created by the political and economic changes. It follows that there are large benefits to be expected from infrastructure improvements.

As the Mendoza - Los Andes corridor is the shortest connection between the economic centres of Chile and Argentina, Brasil, Uruguay and Paraguay, it absorbs the majority of international transits. In 1994 all freight and 93.3% of passenger transits (both excluding air transportation) between Chile and Argentina used the Mendoza - Los Andes corridor (E.F.DP.43)⁷⁶. 85% of the Argentinian population is living in proximity to the axis Buenos Aires - Mendoza - Los Andes - Santiago (E.F.D.70).

These facts evidence the extraordinary importance of the Mendoza - Los Andes transportation corridor for regional economic development in general and suggests, in particular, that an improvement of the link is only a question of time. Our goal in the following, then, is to determine the optimal time and the optimal technology for an improvement of the corridor, applying the methodology developed in Part I. Of course the status quo is the base line for this analysis.

We investigate six technological options to operate the Mendoza - Los Andes transportation corridor in detail:

1. Status Quo Option - transits⁷⁷ via existing road;

2. New Road Option - transits via low altitude road tunnel;

3. Train Shuttle Option - transits via road to low altitude tunnel and via train shuttle through low altitude tunnel;

4. Alternative Shuttle Option - transits via road to low altitude tunnel and via an alternative shuttle system through low altitude tunnel;

⁷⁶ This “drastic” distribution of traffic among the binacional corridors might be partly explained by data collection.
⁷⁷ A transit is a trip from Mendoza to Los Andes or vice versa.
5. Transandino Rail Option - transits by train shuttle through low altitude tunnel;

6. Transandino Alternative Shuttle Option - transits by alternative shuttle system through low altitude tunnel.

The technological attributes relevant for determining the cost structure for each option are described in Chapter 4.

We consider the existing mountain pass and the proposed tunnel as one link, thereby creating a natural monopoly situation. As the assumptions 1-4 of a "transportation project" as set out in Section 2.1 are also satisfied, the application of the framework (the validity of which was "deduced" from these assumptions alone) to the Mendoza - Los Andes transportation corridor is warranted.

Due to information constraints, the evaluation of the project is characterised by shortcuts and simplifications and, thus, the economic analysis in parts degenerates into a financial analysis. We remember from Section 1.2 that the difference between the economic and financial analysis is a function of the impact of the project in the markets for inputs and outputs, the degree of distortedness in the markets for inputs and outputs and externalities. It is beyond the scope of the thesis to quantify this aggregate difference, or in other words to conduct a thorough economic analysis. Note, however, in defense of the analysis conducted that the difference between an economic analysis and a financial analysis is to be expected to decrease as market distortions are reduced in the process of market liberalization. Furthermore, major economic costs such as safety and the value of time are considered in the analysis.

It follows that the difference between the analysis conducted and a more thorough economic analysis does not vitiate the results of the analysis. If the project is found attractive enough to warrant more research, further replacing financial by economic values is certainly a good idea.
A distributive analysis, i.e. disaggregating costs and benefits of the options with respect to whom they accrue, is far beyond the scope of this paper. The possibility of sufficiently negatively affected entities with veto power, alone, indicates that a distributive analysis ought to be conducted if the project is found to be sufficiently attractive.\[78\]

We proceed in four steps: In Chapter 4 the cost structure per year of the six options is analysed. In Chapter 5 the benefits per year are estimated for given demand curves. Some estimates are made as to future developments in demand, i.e. demand curves and time are correlated. In Chapter 6 the results of Chapters 4 and 5 are synthesised yielding net benefits per year for each option as a function of given demand curves, and assuming demand scenarios, as a function of time. In Chapter 7 the results are discussed.

The main source document for the investigation is the “Estudio Prefactibilidad Mejoramiento Conexion Internacional Zona Central (Chile) Y La Region Cuyo (Argentina)” conducted by Consorcio Juan Pablo II (R&Q, Geoconsult, HYTSA) jointly commissioned by the Argentinean and the Chilean governments. That document (referred to by “E.F.”) consists of four parts:

1. Informe Diagnostico Y Propuesta (Version Corregida), referred to as E.F.DP. The string of symbols E.F.DP.13, then means, Estudio Prefactibilidad, Informe Diagnostico Y Propuesta, page 13.

2. Estudio de Factibilidad Tecnica Tunel a Baja Altura, referred to as E.F.T.

3. Estudio de Demanda, referred to as E.F.D

4. Evaluacion Economico-Financiera, referred to as E.F.EF.

\[78\] See Sections 1.1, 1.2.
The analysis in this thesis could thus be described as thinking through the policy implications of the facts as stated in the document - only minor additional assumptions are made. The serious reader is encouraged to study the above document (although, we note, that it is written in Spanish).

Before embarking on the analysis a satisfactory answer is to be provided for why an additional feasibility study based on very similar data might be fruitful. The following is a list of differences between the feasibility study conducted in E.F.EF. and our study which justify the expectation of new insights:

1. In E.F.EF. the economic benefits of an investment option are determined by the savings in operating costs relative to the status quo option. In our analysis, the economic benefits of the investment option are based on the willingness to pay of consumers of transits;

2. We consider three technical options ignored in E.F.EF.

3. In contrast to E.F.EF. we incorporate costs due to safety in the cost-benefit analysis.

Note that this list is not intended to provide a comparative analysis of both approaches. It does, however, warrant expending the effort to conduct an additional economic cost-benefit analysis.
CHAPTER 4: COST ANALYSIS OF OPTIONS

4.1 GENERAL REMARKS - PARAMETERS APPLICABLE TO ALL OPTIONS

The complete set of assumptions made, calculations conducted and results for each section is exhibited in tabular and diagramatic form in the Appendix and in the Figures. In the text only the less obvious or more critical assumptions and results are discussed. For a more detailed technical exposition consult E.F.T.

We assume that the variability of outcomes (risk) is not a cost, i.e. the project should be evaluated with respect to expected net benefits, alone. Let us justify this assumption.

We argued in Section 1.4 that if a government conducts many and statistically independent projects and if the project is sufficiently small then risk should not be perceived as a cost. The underlying reason is that each individual taxpayer has a small share in a large number of projects that are statistically independent. In such a portfolio of projects risk of the outcomes of the projects in aggregate is negligible. As risk of each individual project is diversified away from the taxpayer’s perspective, it is not perceived as a cost from the taxpayer’s perspective, and, derivatively, ought not to be perceived as a cost from the government’s perspective.

Thus, in order to justify our assumption we need to corroborate the claim that the stake for each individual taxpayer in the Mendoza-Los Andes project is small enough as to be diversified away in the overall portfolio. We conduct a “back of the envelope” type of reasoning: The economy comprising the Chilean and the Argentinean economy has approximately 46 million people; Assuming the ratio of taxpayers to non-taxpayers to be 1:3 (i.e. an average household of 4) yields 11.5 million taxpayers; In the “most expensive” option, the New Road Option, yearly capital costs are estimated to be $500 million; It follows that each taxpayer has a share of $43 of capital costs per year; This is small enough as to be diversified away in his overall portfolio of public projects (the crucial
step); Thus, no risk is perceived by the individual taxpayer, and derivatively, risk ought not to be treated as a cost in the analysis.

At a later stage in the evaluation and design process of the project it might be advisable to determine whether risk neutrality is indeed the right risk attitude to take, and if not, to determine the expected variance of the outcomes for each option. At our stage of analysis the argument is sufficiently plausible.

Note that, from a risk spreading perspective, it would be preferable to finance the project on the basis of what might be called the “Mercosur Infrastructure Development Fund”, as risk is spread among a larger number of taxpayers.

As discussed in Section 2.3 fixed costs are those costs that accrue independently of the quantity of transits, variable costs are those costs that are a function of quantity of transits. All costs are given per year unless otherwise stated.

Whenever available economic prices are used rather than financial prices. All costs and benefits are stated in real terms in 1995 United States Dollars (this unit is referred to in the following by the symbol $). We assume that relative prices, i.e. the quotients of the prices between any two goods, remain constant.

The economic opportunity cost of capital (discount rate) in E.F.E. is assumed to be 12% constant through time (E.F.E.22). This is consistent with the 12.68% estimate of the economic opportunity cost of funds as conducted in “Financial and Economic Feasibility of a Mobile Natural Gas Supply System for Rural Villages” (p.22) based on elasticities of supply of funds by households, business, government and foreign and on elasticities of demand of funds by households, business and government in Argentina.

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79 An additional argument supporting the idea of such a fund is that benefits of the improved link would also accrue to other Mercosur countries, in particular Brazil, Uruguay and Paraguay.

80 Note that in E.F.T274 an inflation of 4% is considered in the prediction of the nominal cost at the end of construction of each option. Dealing in nominal values is perilous, due to the difficulty of predicting inflation. It clouds the essentially interesting information: Real cost. Is 10 million USD in 2010 a lot?
The economic opportunity cost of equipment is estimated by the conversion factor\(^{81} 1\) (E.F.E.61). This compares to a conversion factor of 1.098 in the above cited study. The difference may be explained by difference of types of equipment in the respective projects. We assume a conversion factor of 1.

The economic opportunity cost of construction is estimated by the conversion factor 0.89 (E.F.E.60). As for equipment, we assume a conversion factor of 1.

The cost of road maintenance and snow removal are assumed to be each $2500 per km per year (E.F.DP.359). For simplicity, maintenance is regarded as a fixed cost.

The cost of travel time is included in the cost of vehicle operation (E.F.D 301). The cost of waiting time at the shuttle terminal, which applies to all options but the Status Quo Option and the New Road Option, is estimated by attributing 80% of the reduction in operation cost at higher speeds as estimated in E.F. to time savings (E.F.D.301). This results in the value of time of $15, $120, $20, $31.25 per hour for cars, busses, trucks and the average vehicle, respectively. As waiting time is a minor factor, the modelling assumption is sufficiently plausible.

Safety costs are expected to be critical as accidents are expected to be much more prevalent in the Status Quo Option as compared to the other options and "accident externalities could be as large as all other externality costs (of traffic) taken together"\(^{82,83}\). The costs of safety in our analysis comprise only the costs of expected fatalities for each option. We distinguish fatality rates for traffic on road in the open, road in the tunnel, rail in the open and rail in the tunnel. The fatality rates for a transit in a given option, then, is a function of the length of its' sections of road and rail, in and out of the tunnel. The prevalence of fatalities is predicted on the basis of historical data:

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\(^{81}\) See Section 1.2; Financial value * conversion factor = economic value.


\(^{83}\) Sensationalist evidence for the relevance of safety in the form of a picture of a truck turned over by strong winds is displayed in Appendix 4. Unfortunately, more helpful information about the link itself for estimating the safety cost in the Status Quo Option is not available.
The fatality rate on roads in Colorado (U.S.A.) in 1989 were 2.5 per 100 million km\(^8\). While admittedly less than ideal, this figure is a plausible estimate for the fatality rate on road sections in the open in the Mendoza - Los Andes transportation corridor as Colorado has similar topography. We assume the fatality rates on open road to be 2.5 per 100 million km.

In Switzerland the fatality rates on motorways in the open and on motorways in tunnels have been found to be similar\(^8\). We assume the fatality rates on road in the tunnel to be 2.5 per 100 million km.

In Germany fatality rates on railroads average 10 per year\(^8\). The total quantity of passenger kilometers in 1989 was 411.4487 (100 million km) resulting in 0.024 fatalities per 100 million km travelled. As this is negligible relative to 2.5 as in the road case in Colorado, we assume that the fatality rate on rail in the open is 0.

While the rate of accidents on rail in tunnels is to be expected to be lower than in the open, as interaction with the environment (e.g. avalanches, animals) is reduced, the fatality rate per accident is to be expected to be higher as the difficulty of rescue mission increases and, in the case of fire, safe areas are less accessible. We estimate that the two effects cancel each other out and assume that the fatality rate on rail in the tunnel is 0.

According to E.F. (E.F.DP.707) environmental impacts are not of first order importance. We, therefore, do not consider environmental costs in our analysis. In higher per capita GDP countries such as the U.S.A environmental costs would play an important role. As the project is long-term and the per capita GDP of Argentina is to be expected to,

\(^8\) Source: H. Bohnenblust “Die Risikobeurteilung als Planungshilfe hinsichtlich der Betriebssicherheit von langen Eisenbahntunneln”.
eventually, reach current U.S. per capita GDP it is advisable to question the assumption at a later stage in the evaluation and design process.

We assume that the proportions of transits via the Mendoza - Los Andes corridor in the categories cars, buses and trucks remain constant at 55:14:31, respectively. This assumption is warranted as not much realism is lost as the proportions have been about constant (cars : bus : truck (in per cent) in the years 1992, 93, 94 respectively: 55:14:31, 56:13:31, 56:13:31; E.F.D.63) and are projected to remain so (56:12:31 in the year 2010 with new tunnel; E.F.D.305,310,314) while the analysis is simplified considerably: We conduct the analysis by calculating the costs of an average vehicle. Based on the costs of operation of cars, buses and trucks, including safety, time, fuel and maintenance the costs of operation ($/km) for the average vehicle are calculated.

We calculate the cost situation for each option for the range of demand between 200,000 and 4,000,000 transits per year in discrete steps of 200,000. Total quantity of transits in 1994 was 295,333.

The demand per day is calculated as a function of quantity of transits per year and a distribution of transits over the year. The distribution of transits is obtained from Mr. M. Boefer at Geoconsult and based on past distributions. We distinguish three periods in the year: The high transit period, comprising the month of January (the summer period), with peak demand; The medium transit period, comprising the months December, February and March, with medium demand and the low transit period, comprising the period April to November, with low demand. The distribution used is consistent with the one used in E.F.EF. (E.F.EF.45). The fact that the link was historically on average 30 days closed during the winter in the past has been considered in the prediction of the distribution of transits throughout the year.

In the case that demand for the Mendoza - Los Andes corridor exceeds capacity during the summer, it is assumed that the excess demand is re-routed via Paso Pehuenche, a detour of approximately 750 km. The costs of re-routing are calculated for the average
vehicle. Note that the cost estimate for re-routing is on the high side: traffic from Mendoza to Los Andes largely has Santiago de Chile or Valparaiso as destination, reducing the detour by approximately 90 km. In the case that demand exceeds capacity during the winter, for instance as a consequence of closure of the link due to snow, the excess demand is re-routed via Paso Puyehue, as Paso Pehuenche is often closed then, too. This results in a detour of approximately 2127 km. The extra cost estimated for re-routing is on the high side as above and also: currently the route is closed due to snow about 3 days at one time (Source: Mr. Boefer, Geoconsult) and while buses use Paso Puyehue, many trucks do not, apparently incurring less cost waiting until it reopens than re-routing. The costs for re-routing do not include so-called pipeline costs such as increased inventory as a consequence of unreliable transportation.

The expected costs due to congestion and closure are only calculated for the Status Quo Option having a capacity of 5000 vehicles per day and a route that is expected to be closed for approximately 15 days in the winter due to snow. The investment options each have an estimated capacity of 10,000 (via new tunnel) + 5000 (via Status Quo Route) vehicles per day, which is far beyond the demand range that needs to be considered to make a decision between the Status Quo and the investment options. It is expected that closure of the link due to snow is negligible in an investment option.

Furthermore, apart from costs due to congestion, the cost per transit is invariant with respect to the quantity of transits on the link. For instance it is not captured that fuel consumption for vehicles is positively correlated with the density of traffic. These assumptions, then, imply the following marginal cost structures per day for the investment options and the Status Quo Option.

The marginal cost curve for the investment options is depicted in Figure 4.1-1. Note that the marginal cost curve (SI-SI') is constant. This is a consequence of the absence of congestion as discussed above.
The marginal cost curve for the Status Quo Option is depicted in Figure 4.1-2. The marginal cost curve consists of three constant lines depending on which route the transit takes place. In the summer (SS1-SS1') up to capacity the marginal cost is that of the Paso Christo Redentor, i.e. the direct route from Mendoza to Los Andes. The transits above the capacity of 5000 vehicles per day are re-routed via Paso Pehuenche at $581 per transit. In the case of demand beyond capacity in the winter the case is analogous to the case in the summer with the only difference that the (constant) marginal cost beyond capacity is higher, namely $1237, as the detour in question is larger (SS2-SS2'). The case that the link is closed due to snow is described in the diagram by setting capacity equal to zero.

We estimate the marginal cost curve of the options per year as a function of quantity of transits per year on the basis of the marginal cost curve per day as presented above by calculating the average per transit increase of variable cost for an increase of an additional 200,000 transits per year: The marginal cost for the transits between 1,000,000 and 1,200,000 transits, for instance, is estimated by [(total variable cost for 1,200,000 transits - total variable cost for 1,000,000 transits) / (1,200,000 - 1,000,000)]. In the following the term “marginal cost curve” refers to the marginal cost curve per year (a function of quantity of transits per year).

As will be discussed in Chapter 6, the marginal cost curve is crucial for the calculation of net benefits in our model. In the following chapter we will estimate the cost structure and and derive the marginal cost curve for each option.
**FIGURE 4.1-1:**  MARGINAL COST CURVE FOR INVESTMENT OPTIONS

**FIGURE 4.1-2:**  MARGINAL COST CURVE FOR STATUS QUO OPTION
4.2 STATUS QUO OPTION

4.2.1 DESCRIPTION

The status quo option refers to operating on the existing route with modest improvements: A mountain road via the Paso Christo Redentor with an altitude of 3148m. The road has a total length of 261 km of which 20 km are in flat, 46 km in hilly and 195 km in mountainous topography. The road is paved throughout.

There are plans (partly executed) on the Chilean as well as the Argentinean side to upgrade the existing connection:

1. The road is to be repaved on large sections (E.F.DP.325);
2. The existing tunnel is to be upgraded (E.F.DP.327);
3. Avalanche protection is to be installed (E.F.DP.327);
4. Slow lanes are to be installed on the Chilean side (E.F.DP.327).

Operating on this upgraded route, then, is referred to as the Status Quo Option.

4.2.2 FIXED COSTS

The investment in the improvement of the link as described above are to be made independently of the decision to build the new tunnel or not and thus have to be regarded as sunk costs (though some of the investments occur in the future relative to 1996). The costs for the existing infrastructure are sunk costs. Hence no capital costs accrue in the Status Quo Option. Fixed costs thus comprise only the maintenance costs and snow removal costs.
4.2.3 VARIABLE COSTS

The capacity is in E.F. estimated to be 5000 vehicles per day. The bottlenecks are the existing high altitude tunnel and the hairpin curves ("caracoles") on the Chilean side. There is conflicting evidence concerning this figure: The calculation for the capacity in E.F. is based on a capacity of 600 vehicles per hour and 8.3 hours of operation of the link suggesting that 5000 vehicles per day is less than the true capacity; Carl Martland (MIT) claims that congestion is already occurring during peak demand of 3000 vehicles per day suggesting that 5000 vehicles per day is an optimistic estimate of capacity. The capacity is subject to a sensitivity analysis.

It is assumed that the route is closed due to snow for 15 days per year during winter time.

The costs of operation per transit in reliable service and unreliable service (either congestion or closure due to snow) are calculated on the basis of costs stated in Section 4.1.

4.2.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.2.4. The results are displayed graphically in Figure 4.2.4.

The graph depicts average fixed cost, average variable cost, average total cost and marginal cost in $ per transit as a function of total quantity of transits per year. As the only fixed costs in the Status Quo Option are maintenance and snow removal costs, and in particular no capital costs as in the investment options, average fixed cost per transit are negligible and coincide with the x-axis. In the virtual absence of average fixed cost per transit the average variable cost per transit coincides with average total cost per transit and is therefore concealed by it.

88 Source: Mr. M. Boefer, Geoconsult.
FIGURE 4.2.4: STATUS QUO OPTION - COST STRUCTURE

[Graph showing cost structure over different transit scenarios]
As is to be expected due to congestion, the marginal cost curve is upward sloping. The precise shape of the marginal cost curve, though, might come as a surprise. The key for understanding the shape is provided in Appendix 4.1 in the section titled "transits per day as a function of transit period and quantity of transits per year". In particular, the table reveals when the assumed daily capacity of 5000 transits is reached during peak, medium and minimum demand (referred to as high, medium and low transit period, respectively).

No congestion occurs on the link up to an annual quantity of transits of 1,000,000. Thus the marginal cost curve is flat up to 1,000,000 transits per year.

At the quantity of transits of 1,200,000 per year the demand for quantity of transits exceeds the capacity by 1000 per day. These 1000 vehicles incur costs of $581 by re-routing via Paso Pehuenche rather than incurring $223 via Paso Christo Redentor, the direct route. At 1,200,000 transits per year no congestion occurs during the medium and low transit periods. As the high transit period only comprises one month (January) the increase in marginal cost is modest.

As the link is still congestion free during the medium and low transit periods at 1,400,000 annual transits and the additional congestion of 1000 transits per day is identical to the increase in congestion between 1,000,000 and 1,200,000 the marginal cost curve remains flat between 1,200,000 and 1,400,000 transits per year.

At 1,600,000 annual transits congestion (=re-routing) of 777 vehicles per day occurs, during the medium transit period. As the medium transit period comprises 3 months the result is a sharper increase in marginal costs. (Congestion during the high transit period increases (from 1,400,000 annual transits) by the same amount and therefore does not increase marginal cost.)

Between 1,600,000 and 2,200,000 annual transits the increases in congestion are the same as between 1,400,000 and 1,600,000 resulting in a flat marginal cost curve.
At 2,400,000 annual transits congestion occurs during the low transit period. As the vehicles are re-routed via Paso Puyehue at a cost of $1237 during the the winter months (June, July, August) and the low transit period comprises 8 months, the marginal cost curve increases sharply.

Beyond 2,600,000 the increases in congestion and thus the increases in variable costs are constant for each interval of 200,000 transits and so is the marginal cost curve.

This explains the surprising shape of the marginal cost curve.

4.3 NEW ROAD OPTION

4.3.1 DESCRIPTION

The transportation corridor between Mendoza and Los Andes is identical to in the Status Quo Option except that the section between Puente del Inca (Argentina) and Juncal (Chile) is connected by a road tunnel of 26.05 km length (E.F.T.068). The tunnel consists of two tubes each with two lanes and one directional traffic per tube. As the geology is expected to be such that using tunnel boring machinery is inappropriate, the more costly and time consuming, traditional method of blasting is to be used.

The road has a total length of 259 km of which 45 km are in flat (including the tunnel), 47 km in hilly and 167 km in mountainuous topography.

The route is displayed in Figure 4.3.1-1 (E.F.T.14)

The configuration of the tunnel is displayed in Figure 4.3.1-2 (E.F.T.80)
FIGURE 4.3.1-1: NEW ROAD OPTION - MAP OF ROUTE
FIGURE 4.3.1-2: NEW ROAD OPTION - SECTIONAL DRAWING OF TUNNEL

$A_1 =$ AREA EXCAVACION TOTAL = 93.89m²

$A_N =$ AREA INTERNA NETA (NECESARIA PARA VENTILACION FORZADA LONGITUDINAL)

VENTILACION FORZADA DE TIPO LONGITUDINAL

REVESTIMIENTO PRIMARIO DE SHOTCRETE

REVESTIMIENTO INTERNO DE HORMIGON IN SITU

DELIMITACION AREA DE TRANSITO

Plano clave sección transversal
4.3.2 FIXED COSTS

Implementing the New Road Option is expected to take 19 years and total accumulated cost (including capital cost during construction) at the end of year 19 are expected to be $4180 million. Thus the capital cost per year during operation, then, is 12% of that or $501 million. To this the maintenance cost of the tunnel ($2.3 million) and road ($0.8 million) are to be added.

4.3.3 VARIABLE COSTS

The capacity of the tunnel is limited to 1000 vehicles per hour as the sum of both directions (E.F.T.111). This limit derives from the ventilation system proposed to be installed.

Ventilation is a major cost in the operation. As ventilation is correlated to quantity of transits ventilation is regarded to be a variable cost calculated on a pro rata basis: \[
\text{ventilation cost per vehicle} = \frac{\text{total annual ventilation cost (calculated for 10000 vehicles per day)}}{365*10000}\]

4.3.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.3.4. The results are displayed graphically in Figure 4.3.4.

The graph is identical to the graph discussed in Section 4.2.4. The cost structure of the New Road Option though is sufficiently distinct to warrant further discussion.

The average fixed cost per transit is a major factor in determining average total cost due to large capital costs. The average marginal cost per transit is equal to the average variable cost per transit and constant as no congestion occurs. The average total cost per
FIGURE 4.3.4: NEW ROAD OPTION - COST STRUCTURE
transit, then, is downward sloping as the capital costs are distributed among a larger number of transits.

As the remaining investment options have a qualitatively identical cost structure we refrain from further discussion of the analogous graphs for the subsequently discussed investment options. The average total costs of the options are compared in Section 4.8. The more revealing net benefits of the options are discussed in Chapter 6.

4.4 TRAIN SHUTTLE OPTION

4.4.1 DESCRIPTION

The transportation corridor between Mendoza and Los Andes is identical to in the Status Quo Option except that the section between Puente del Inca (Argentina) and Juncal (Chile) is connected by a rail tunnel of 23.02 km length (E.F.T.15). The rail tunnel consists of two single rail tubes. 8.45 km of the 23.02 km is constructed with open ceiling (false tunnel). The balance is constructed with tunnel boring machinery. Using tunnel boring machinery as compared to the traditional method of blasting to be used in the New Road Option considerably reduces capital costs and time of construction.

In the shuttle operation, cars, buses and trucks are transported on flat-cars powered electrically by locomotives between the two shuttle terminals located in proximity to the respective tunnel portals. Extensive experience with this system exists as it has been applied for some time in the Alps, for instance in the Loetschberg tunnel and Vereina tunnel, Switzerland and the Boeckstein tunnel, Austria. The Channel tunnel operates such a train shuttle system in addition to the trains connecting the French and English rail networks.

Using an electric powering system as compared to a combustion based powering system as in the New Road Option has two advantages. Firstly, the supply of fresh air, which is the critical issue in the determination of the capacity of the road tunnel, is unproblematic.
Secondly, a large percentage, approximately 60%, of the energy expended to move the vehicle up from the Chilean to the Argentinian side is recouped in the braking process by the trains from the Argentinian to the Chilean side.

The route consists of 24 km rail, operated by train shuttle, and a total of 232 km of roads of which 18 km are in flat, 47 km in hilly and 167 km in mountainous topography.

The route is displayed in Figure 4.4.1-1 (E.F.T.15)

The configuration of the rail tunnel is displayed in Figure 4.4.1-2 (E.F.T.089)

Note that the gradient of the route is 5% (E.F.T.148). According to Prof. H. Einstein (MIT) it is highly implausible due to the low friction coefficient of steel on steel that a route with gradient of 5% is optimal for a rail tunnel. Rail shuttle tunnels in Switzerland do not exceed 2.5%.

4.4.2 FIXED COSTS

Implementing the train shuttle option is expected to take 11 years and total accumulated construction cost are expected to be $1210 million, translating into capital cost per year of $145.2 million per year of operation.

Investment in the transport park, mainly locomotives, is not regarded as a fixed cost but assumed to vary with the quantity of transits on a pro rata basis.

The maintenance cost of the road portion of the link is calculated as above. The maintenance cost of the tunnel, excluding maintenance of transport park, are $0.419 million.
FIGURE 4.4.1-1: TRAIN SHUTTLE OPTION - MAP OF ROUTE
FIGURE 4.4.1-2: TRAIN SHUTTLE OPTION - SECTIONAL DRAWING OF TUNNEL

Plano clave sección transversal
4.4.3 VARIABLE COSTS

In the E.F. capital costs and maintenance costs of the transport park as well as operation costs are calculated to provide a capacity of 10000 vehicles per day. Clearly if the quantity of transits are considerably lower, fewer locomotives will be acquired and less electricity etc. will be consumed. In order to capture this relation in the model, we assign 1/10000 of the cost indicated in E.F. to each vehicle. This provides a bias in favor of the option as a minimum capacity has to be maintained as waiting time otherwise becomes unjustifiable. If the findings are favourable to this option these simplifying assumptions will have to be dropped.

The cost as a consequence of the value of time on the rail portion of the transit are calculated based on the value of time stated in Section 4.1 and average waiting and travel time, 0.5 hour each.

4.4.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.4.4. The results are displayed graphically in Figure 4.4.4.
FIGURE 4.4.4: TRAIN SHUTTLE OPTION - COST STRUCTURE

- Average fixed cost per transit
- Average variable cost per transit
- Average total cost per transit
- Marginal cost (extra 200,000)

$ per transit vs. transits/year
4.5 THE ALTERNATIVE SHUTTLE OPTION

4.5.1 DESCRIPTION

The Alternative Shuttle Option is identical to the Train Shuttle Option apart from the powering system. While in the Train Shuttle Option conventional locomotives are used, in the alternative shuttle option electrically powered "platforms" each carrying either 2 cars or 1 bus or 1 truck are used. This type of powering system has not been implemented so far and the information available thus has to be taken with "a pinch of salt". A picture of such a platform is displayed in Figure 4.5.1.

The platforms are powered electrically so that, as in the Train Shuttle Option, a high percentage, approximately 60%, of the energy expended to move the vehicle up from the Chilean to the Argentinian side is recouped in the braking process by the platforms from the Argentinian to the Chilean side.

There are two immediate advantages of the alternative shuttle system over the train shuttle system. The frequency of service in the alternative shuttle system is higher as the platforms carry only one or two vehicles resulting in an avoidance of waiting time. As the friction coefficient of rubber on road (asphalt, concrete) is markedly higher than the friction coefficient for steel on steel the gradient of 5% of the route is unproblematic.

The route is displayed in Figure 4.4.1-1 (E.F.T.15).

The configuration of the alternative shuttle tunnel is displayed in Figure 4.4.1-2 (E.F.T.089).
FIGURE 4.5.1: ALTERNATIVE SHUTTLE OPTION - PICTURE OF PLATFORM
4.5.2 FIXED COSTS

Implementing the alternative shuttle option is expected to take 11 years and total accumulated construction costs are expected to be $1025 million, translating into capital costs per year of $123 million per year of operation.

As in the train shuttle, we consider capital costs and maintenance of the transportation park to be a variable costs.

The maintenance costs of the road portion of the link is calculated as above. The maintenance costs of the tunnel, excluding maintenance of transport park, are $0.474 million.

4.5.3 VARIABLE COSTS

As in the train shuttle case the capital costs and maintenance costs of the transportation park are taken as variable costs and are calculated on a pro rata basis. The underlying assumption that the transportation park is extended as demand rises, however, is very plausible in the alternative shuttle case. Apart from this modelling assumption being more plausible in the alternative shuttle case than in the train shuttle case, and more importantly, there is a sizable real advantage of the Alterantive Shuttle Option: Capacity can be increased practically continuously.

Due to the reduced loading and unloading (waiting) time the average total trip time is only 0.525 hrs.

The costs due to safety is assumed to be identical to the rail case.

The costs of operation and transportation park as estimated in E.F.T. appears to be rather low at 5$ per transit for the shuttle portion of the transit (Prof. H. Einstein, MIT).
4.5.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.5.4. The results are displayed graphically in Figure 4.5.4:
FIGURE 4.5.4: ALTERNATIVE SHUTTLE OPTION - COST STRUCTURE

- average fixed cost per transit
- average variable cost per transit
- average total cost per transit
- marginal cost (extra 200000)

transits/year

$\text{transit}
4.6 TRANSANDINO RAIL OPTION

4.6.1 DESCRIPTION

The Transandino Rail Option is not analysed in E.F.EF. In this sense, the option is created by the Author.

In the Transandino Rail Option the existing right of way of the old transandino railway between Mendoza and Punta del Inca on the Argentinian side and between Juncal and Los Andes on the Chilean side is to be rehabilitated. The section between Punta del Inca and Juncal is as in the Train Shuttle Option. The terminals for the shuttle would be located in Mendoza and Los Andes.

The old transandino railway has been out of service since 1983 and is in a very damaged condition due to military action during the war between Chile and Argentina in 1984 (Source: Mr. Boefer, Geoconsult). The width of the transandino railway is 1000 mm as compared to the standard “Spanish” width of 1676 mm in Argentina and Chile. It is therefore to be expected that the cost of rehabilitation is to be substantial.

The obvious benefit of this option is that it affords a rail link between Argentina and Chile and in particular between the economic centres Buenos Aires and Santiago de Chile/Valparaiso.

4.6.2 FIXED COSTS

The capital costs for the Punta del Inca - Juncal portion is as in the Train Shuttle Option (including cost of terminals). The costs for the rehabilitation of the tracks Mendoza - Punta del Inca, Juncal - Los Andes is estimated at $7 million per km by Herrman Koehne Ltd.. This estimate is derived on the basis of an actual rehabilitation of a railroad track: A
conversion of 26 km of single track out of service since 1950 into double track cost DM 275 million\textsuperscript{89} in 1990.

The maintenance costs for the Punta del Inca - Juncal portion is as in the Train Shuttle Option. The costs of the maintenance for the tracks Mendoza - Punta del Inca and Juncal - Los Andes is estimated at $10000 per km and year. This estimate is based on the results of a cost-benefit analysis comparing track on ballast with track on concrete conducted for the “Rhein-Main” project - a new rail link between Cologne and Frankfurt (estimated total investment cost: $4 billion).

The costs of the transportation park is, as in the Train Shuttle Option assumed to be variable.

4.6.3 VARIABLE COSTS

The capital costs and maintenance costs of the transportation park and operations costs are directly proportionally extrapolated from 23 km service (Train Shuttle Option) to 255 km on a pro rata basis.

This is an even more tenuous approach than in the Train Shuttle Option: In order to keep travel time satisfactory the transportation park has to be sizable (i.e. costs are understated); As the electricity requirements and locomotive requirements for the flat/hilly terrain between Mendoza - Punta del Inca and Juncal and Los Andes are taken from the 5% gradient section, costs are overstated. Note, though, that the divergence of costs due to electricity is less than might be expected as approximately 60% of the energy expended as a consequence of the gradient is recouped in the breaking process. If the Transandino Rail Option looks attractive enough in this analysis to warrant further attention, then developing a more realistic operating cost model is a high priority.

\textsuperscript{89} The DM 275 million disaggregate into: Railroad construction: DM 133 million; Signaling: DM 12 million; Bridges: DM 90 million; Engineering Services: DM 40 million.
Total travel time between Mendoza and Los Andes is 3.05 hrs.

4.6.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.6.4. The results are displayed graphically in Figure 4.6.4.
FIGURE 4.6.4: TRANSANDINO RAIL OPTION - COST STRUCTURE

- average fixed cost per transit
- average variable cost per transit
- average total cost per transit
- marginal cost (extra 200000)
4.7 THE TRANSANDINO ALTERNATIVE SHUTTLE OPTION

4.7.1 DESCRIPTION

The Transandino Alternative Shuttle Option is not analysed in E.F.EF. In this sense, the option is created by the Author.

The Transandino Alternative Shuttle Option is the natural combination of the Alternative Shuttle Option and the Transandino Rail Option.

The Transandino Alternative Shuttle Option may be upgraded to provide through rail service at "little extra cost". We do not pursue this issue any further.

4.7.2 FIXED COSTS

The capital costs for the portion Punta del Inca - Juncal is as in the Alternative Shuttle Option. The capital costs for the portions Mendoza - Punta del Inca and Juncal - Los Andes is assumed to be identical as in the Transandino Rail Option.

Capital costs and maintenance costs for transportation park are assumed to be variable.

Maintenance costs of the infrastructure is as in the Alternative Shuttle Option and Transandino Rail Option for the respective portions.

4.7.3 VARIABLE COSTS

The capital costs and maintenance costs of the transportation park and operations costs are directly proportionally extrapolated from 23 km service (Alternative Shuttle Option) to 255 km on a pro rata basis. For the same reasons as in the discussion of the Alternative Shuttle Option this assumption is very much less problematic than in the Transandino Rail Option.
Total average travel time between Mendoza and Los Andes is 2.55 hrs.

Costs due to safety is assumed to be identical to the rail case.

4.7.4 SYNTHESIS OF COSTS

The cost structure is displayed numerically in Appendix 4.7.4. The results are displayed graphically in Figure 4.7.4.
FIGURE 4.7.4: TRANSANDINO ALTERNATIVE SHUTTLE OPTION - COST STRUCTURE

- average fixed cost per transit
- average variable cost per transit
- average total cost per transit
- marginal cost (extra 200,000)
4.8 COMPARISON OF AVERAGE TOTAL COSTS OF OPTIONS

We remember from Section 2.2 that using the decision principle “Choose option that minimizes average total cost for the expected range of quantities of transits” may lead to a suboptimal choice from the economic perspective because the quantity of transits is a function of level of service; In other words, the demand side is ignored. However, if users are to be made to pay their way, this result indicates the cost they should incur as a function of quantity of transits. Before we incorporate the demand side into the analysis in the next chapter we here investigate the options along the average total cost dimension. As the results are only of limited usefulness, the discussion is brief.

The comparison of average total costs of the options is displayed numerically in Appendix 4.8 and graphically in Figure 4.8:

By inspection, we see that the Status Quo Option has the lowest average total cost up to about 1.6 million transits per year. From 1.6 million to 2.5 million transits per year operating the Alternative Shuttle Option provides the lowest average total cost. From 2.5 million to 4 million transits per year operating the Transandino Alternative Shuttle Option provides the lowest average total cost per transit. To help gauge these findings note that in 1994 the actual quantity of transits was 295,333 vehicles. The prediction of demand is conducted in detail in the following chapter.

The Transandino Rail Option is the worst of the investment options. This is explained to a large extent by the high costs for the transportation park of operating a shuttle service for about 260 km.

The New Road Option is superior to the Status Quo Option for more than 2.8 million transits, i.e. when congestion is very painful already: about 70% of transits are re-routed to an alternative mountain pass in the model.
FIGURE 4.8: COMPARING AVERAGE TOTAL COST

<table>
<thead>
<tr>
<th>Option</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo Option</td>
<td>✗</td>
</tr>
<tr>
<td>New Road Option</td>
<td>□</td>
</tr>
<tr>
<td>Train Shuttle Option</td>
<td>△</td>
</tr>
<tr>
<td>Alternative Shuttle Option</td>
<td>○</td>
</tr>
<tr>
<td>Transandino Rail Option</td>
<td>●</td>
</tr>
<tr>
<td>Transandino Alt. Sh. Option</td>
<td>■</td>
</tr>
</tbody>
</table>

Cost vs. Transit/year graph.
This illustrates that considering average total costs does not provide the decision maker with sufficient information: Given the high cost as perceived by the consumer of transits (the driver) in the case of re-routing or congestion it is to be expected that the demand at the same point in time is markedly higher in the New Road Option as in the Status Quo Option.\footnote{We assume, of course, that the price perceived by the consumer is the economically efficient price and not average total cost (See Section 2.2).}

This discussion of average total costs ought to suffice as we will estimate the, more revealing, net benefits for each option as a function of demand curves in Chapters 5 and 6.
CHAPTER 5: BENEFITS

5.1 A NOTE ON METHODOLOGY

In Sections 1.2 and 2.3 we developed a methodology for determining the economic benefits of a project in general. As a proper understanding of the basic ideas involved is crucial for an understanding of the analysis, the interpretation of the methodology to the Mendoza - Los Andes transportation corridor is warranted. Such an interpretation will also serve as an illustration to the discussion of Sections 1.2 and 2.3.

Consider Figure 5.1.

The vertical axis measures the price which each successive unit of transit (i.e. its consumer) would be willing to pay. The horizontal axis measures quantity of transits. The line DD', then, may be interpreted as indicating how much consumers are willing to pay for transits, where the transits are ordered on the horizontal axis from left to right according to the willingness to pay of the respective consumer of the transit. The line DD' is referred to as demand or willingness to pay curve. As different consumers value transits differently (and different transits differently) the demand curve is downward sloping: For instance a manufacturer of tires in Mendoza earning an extra $1000 per truckload in the Chilean market values the transit higher than a manufacturer of shoes who only earns an extra $50 per truckload.

Note that the demand curve indicates the maximum amount the consumer is willing to pay for that unit, i.e. the demander is indifferent between having that particular unit of transit at that particular price or spending his money on whatever other goods and services are available to him at their respective prices. Moreover, the alternatives in question may be very complex. A consumer's willingness to pay for a transit may be determined by the trade-off between the "purchase" of a transit and selling one's produce in the Argentinean market (in the case of freight) or a trip to Buenos Aires (in the case of tourism by an
FIGURE 5.1: DERIVING GROSS BENEFITS

price/transit

D
p
p*
Q
Q*
don quantity of transits
Argentinean in Mendoza). All these choices are reflected in the demand price or the willingness to pay for that transit by that individual.

From these observations it follows that, given a price faced by the consumer, the demand curve indicates the quantity of demand: All consumers willing to pay more than the price will consume. The others will not consume. The quantity consumed, then, is the x-coordinate of the intersection of \( y = \text{price} \) and the demand curve. Consider again Figure 5.1. At price \( P \) the demand curve \( DD' \) implies (conceptual implication!) that \( Q \) transits are consumed. At the lower price \( P^* \), more transits, \( Q^* \), units are consumed. At price \( P \) the gross benefits of the transportation link are measured by the area under the demand curve from 0 to \( Q \) as this measures the value to the consumer. To obtain net benefits from the collective perspective of the consumers subtract \( PxQ \), i.e. total costs as perceived by the consumer, from gross benefits.

In our analysis, though, we are not interested in costs from the consumers perspective but from the economic perspective and we thus subtract total costs for that quantity of transits as derived in Chapter 4 (in the section synthesis of costs).

Lastly, note that at a lower price the gross benefits are larger. In a sense the demand curve contains all the information we need to know in order to determine the benefits of the transportation link: All the value created by the transportation corridor in the market of transits is measured by the area under the demand curve between 0 and the actual quantity of transits.

Benefits that are not included in such an analysis are of the following type: As a consequence of an improvement in the transportation link a car factory is built in Mendoza creating 2000 jobs and paying wages that are 10% above the opportunity cost of labour.

The 10% of net benefits created in the labor market, or for that reason in any other market
related to the output of the project, are not included in such an analysis. Note, however that the benefits due to the extra demand for transits as a consequence of the car factory exporting to Chile are incorporated in the analysis.

Another benefit of the project which we do not incorporate is the reduction of the probability of war between Argentina and Chile -the last one was in 1982- as increased traffic as well as the project as such is to be expected to increase integration among both countries.

As we do not include the above two types of benefits of the improvement of the link our estimate of the benefits are likely to be on the low side. So, if the project is attractive in our analysis then it is attractive if the above benefits are included. In the case that the project is found to be not promising, the above benefits ought to be included in a next step in order to determine whether that changes our verdict.

As argued above, all benefits of the project in the market for transits are captured using the demand curve. This, then, leads us to a problem of information: How to predict how many factories will be built or, more generally, how to predict future demand curves?

5.2 BENEFIT ANALYSIS APPLIED

We were reminded in the preceding section of both the importance and the difficulty of predicting future demand curves. For that reason we will, in this section, derive gross benefits as a function of demand curves, i.e. treating demand curves as an independent variable, and discuss some approaches to estimate future demand curves, i.e. discuss some approaches to correlate demand curves with calendar time. We defer any discussion as to the probability distribution over future rates of growth until we synthesize benefits and

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91 In fact, such benefits are ignored in our analysis of the Mendoza - Los Andes transportation corridor due to a lack of not completely arbitrary estimates. Depending on the outcome of the analysis this working hypotheses (benefits in external markets = 0) may need to be questioned.
costs in the following chapter. This will clarify the information requirements to make a justified choice among the considered options.

The shape of the demand curve for the average vehicle, i.e. the first derivative, is deduced on the basis of predictions of quantities of transits as a function of toll in the year 2010 in E.F.D (E.F.D.305-332). The calculations are displayed in Appendix 5.2-1. The demand curve predicted for the year 2010 with respect to some assumptions is displayed in Figure 5.2-1 (the assumptions are not very interesting in this context as we are only interested in the shape of the demand curve). The shape of the demand curve is assumed to be linear and constant through time. This assumption is a prevalent practice in cost-benefit analysis\textsuperscript{92}.

We describe demand curves using the concept of “demand equivalents”. As this concept has to my knowledge not been used in the literature, some care must be taken to define its’ meaning. Note that a demand curve, assuming that it is a line is uniquely defined by a point in the price - quantity space. Conventionally, lines are described using the y-intercept. For increased clarity we adopt a different convention: We define a demand curve by its’ intercept of the price = $277 line, i.e. the point (# of transits at that price, $277). The x-coordinate is referred to as the demand equivalent. In the year 1994 the cost per transit perceived by the consumer is estimated at $277 and the quantity of transits were 295,333. Hence, the underlying demand curve is described by the demand equivalent = 295,333.

The advantage of this way of defining the demand curve is this. As one has more information about demand at the current price, it is to be expected that projections in demand are of the following kind: Assume, for instance, that when the price for a transit remains constant, we expect growth in quantity of transits of 10%. This is, then, equivalent to saying that the demand curve expected for next year is the one described by the demand equivalent of $(1 + 10\%) \times 295333 = 324,866$. The demand equivalent

\textsuperscript{92} For example, linear demand and supply curves are assumed throughout in: G. Jenkins, A. Harberger "Cost-Benefit Analysis of Investment Decisions" Harvard Institute of International Development, 1996.
FIGURE 5.2-1: SHAPE OF DEMAND CURVE

\[ y = -0.0007x + 797.65 \]

\[ R^2 = 0.9882 \]
describes what would be the demand in a given demand situation were the price of transits perceived by the consumer to be $277.

On the basis of the demand curve described, it is possible to estimate the quantity of transits for different prices, and derivatively the gross benefits as a function of price. As price is correlated to the type of technological option we choose, we can determine the gross benefits for a given demand curve as a function of the option.

It should not be forgotten that using demand equivalents is only a neat way to describe demand curves. It does not in any way solve the problem of predicting future demand curves. The question remains how to reasonably predict growth rates of transits in the Mendoza - Los Andes transportation corridor. In the remainder we will consider some approaches.

We start by considering simple induction: The growth rates of transits via the existing high altitude tunnel in the period from 1986 to 1994 have been -4%, 25%, 47%, 0.5%, 22%, -7%, 2% and 10%, per year respectively. The negative growth rate in 1993 is attributable to an unusually severe winter that caused the link to be closed for extended periods of time. A meaningful trend is not discernible.

The E.F.D. forecasts a growth rate of quantity of transits in the range of 3% (minimum) to 9% (maximum) (E.F.D.(201/202/222/223/260/261)) up to the year 2010. Then, assuming that the tunnel is in place in 2010, it is assumed that the growth rates will be between 5% and 12% up to 2015, between 5% and 10% up to 2020 and then between 2% and 10% up to the year 2040. The forecast is based on a complex destination-origin model of traffic flows based on current transportation and economic trends. It is up to the reader to judge the usefulness of annual demand growth forecasts 45 years hence. In the

93 One interesting finding in the destination-origin model is that exports from Argentina to the Pacific Rim countries constitute only 8% of all exports through the Mendoza customs (read: via Mendoza - Los Andes corridor)(E.F.D.93). This contovers popular opinion that Pacific Rim trade will have a major impact on demand for transits.
terminology developed in chapter 1.4, the E.F.D. is taking the “inside view”. Let us now consider an “outside view”.

One way to forecast demand of transits is to consider trade as a main cause of international traffic. Since E.F.D. was compiled, Chile has joined Mercosur94. Note that this state of affairs is not explicitly considered in the E.F.D. This is an example of the problems with focussing on extrapolating from current trends. It is plausible to expect that trade between Chile and other Mercosur members will develop similarly to trade among Mercosur members so far (what was referred to in Section 1.4 as “the class of cases chosen to be similar”): Since Mercosur’s inauguration in 1991 trade among member countries has increased by 50%, 29%, 20%, 31% in the years ‘90 to ‘91 ... ‘93 to ‘94, respectively95. Unfortunately, no helpful information is available as to the correlation among trade and international traffic or, in particular, transits demanded on the Mendoza - Los Andes transportation link96. What can be said is this: Assuming (1) that trade between Chile and Mercosur in the period between 1996 and 2000 behaves similarly to trade among Mercosur countries from from 1990 to 1994, (2) a direct linear correlation of trade and traffic and (3) a proportional distribution of traffic among the different international transportation corridors, implies annual growth rates for the period of 1996 to 2000 of about 30%.

A basis for a longer term prediction of demand for transits for the Mendoza - Los Andes corridor is provided by comparing future traffic in southern South America to past traffic in another common market, the European Community (EC). Let us compare Chile with Spain and Mercosur with the EC and explore traffic between Spain and the EC to derive expectations about future traffic between Chile and Mercosur. After six years of negotiations Spain became a full member of the EC in 1986 and was granted a

94 Source: The Economist, June 29th 1996
96 Linear regression analysis on the available data indicates that for a 1% increase in trade, transits increase by 0.00263% with an r-squared of 0.0053, i.e. no correlation (see Appendix 5.2-3 and Appendix 5.2-4). We ignore this result by distrusting the trade figures.
transitionary period of seven years to align its laws and regulations with the EC directives\textsuperscript{97}. Considering the remaining trade barriers between Chile and Mercosur and, at best, a medium to long term prospect of their removal\textsuperscript{98} it is plausible to compare the situation of Spain with respect to economic integration into the EC in 1980, when negotiations started, to the situation of Chile with respect to economic integration into Mercosur in 1996.

Now, the average annual growth rate of freight transportation crossing the Pyrenean mountains, i.e. transportation between Spain and central European countries, from 1986 to 1989 was 15\%\textsuperscript{99}. Thus, the analogy suggests, using the above assumption (3) and assuming (4) that the price of transportation in real terms remained sufficiently similar, that annual growth rates in freight transportation between Chile and Mercosur will increase on average by about 15\% over the time period 2002 to 2005. Assuming (4) identical growth rates for passenger transportation, the analogy then suggests the same conclusion for overall transportation. It is plausible to expect that growth rates before that are not going to be lower which leads us to expect that growth rates from 1996 to 2005 are converging to 15\% from above.

An even longer term prediction of demand for the Mendoza - Los Andes transportation corridor is provided by comparing Chile with Italy. This might be an even better analogy than Spain, as many goods transported through the Alps from central Europe to Italy go on to other mediterranean countries by ship, which compares closely to Mercosur access to the Pacific via Chilean ports.

\textsuperscript{97} Source: M. Galy, G. Pastor, T. Pujol “Spain : Converging with the European Community” Occasional Paper 101, International Monetary Fund.

\textsuperscript{98} "... Mercosur has much work ahead. .... Chile ... has negotiated exemptions from completely free trade in wheat and flour for up to 18 years."; Source: The Economist June 29th 1996.

Italy joined the EC in 1957\textsuperscript{100}. The average and fairly constant annual growth rates of transalpine freight traffic from 1970 to 1989 through France, Switzerland and Austria were 7.8%, 2.5% and 7%, respectively\textsuperscript{101}. The low growth rates of freight traffic through Switzerland is explained by Swiss transit policies increasing the cost of transit relative to France and Austria. By analogy, with the above assumptions in place, then, it is suggested that growth rates of demand for transits for the Mendoza - Los Andes transportation corridor in the period from 2006 to 2027 is about 7%.

In Appendix 5.2-2 the correlation of demand equivalents, i.e. demand curves, and calendar time \textit{assuming} the above demand scenarios is derived: (annual growth rates of demand (at $277)) of 3% - the minimum predicted by the E.F.; 7% - the medium and most likely predicted by the E.F; 12% - the maximum predicted by the E.F; 30% - suggested by Mercosur growth rates in trade and, finally, 15% until 2005 and 7% thereafter - suggested by the Mercosur - European Community analogy. The results are displayed graphically in Figure 5.2-2.

Figure 5.2-2 correlates demand equivalents and calendar time as a function of the above defined annual growth rate scenarios. The figure is self-explanatory.

As noted in the beginning of this section we defer any discussion as to the probability distribution over future rates of growth until we synthesize benefits and costs in the following chapter as this will clarify the information requirements to make a justified choice among the considered options and minimize idle speculation.

\textsuperscript{100} P. Vanicelli "Italy, Nato and the European Community" Harvard Studies of International Affairs, No. 31, 1974.

\textsuperscript{101} Calculations based on data from: European Conference of Ministers of Transport "European transport trends and infrastructural needs" OECD, p.50
FIGURE 5.2-2: DEMAND EQUIVALENT VS. TIME AS A FUNCTION OF ANNUAL GROWTH RATE SCENARIOS
CHAPTER 6: SYNTHESIS OF BENEFITS AND COSTS

6.1 - 6.8 NET BENEFITS IN ABSOLUTE TERMS

This section serves as reference to the calculations conducted in the Appendix:

The calculations of net benefits for each option are displayed in Appendices 6.2 to 6.7 and are summarized numerically in Appendix 6.8-1 and graphically in Appendix 6.8-2. The method of calculations is set out briefly in Appendix 6.1.

The discussion of net benefits is conducted in the following section.

6.9 NET BENEFITS RELATIVE TO THE STATUS QUO OPTION

In Chapter 4 we have determined the cost structure for each of the six of the technological options considered for the Mendoza - Los Andes transportation corridor per year. In Chapter 5 we developed a method to determine gross benefits of the corridor per year given a demand curve and price for transits and investigated ways to forecast demand for the future. In this chapter we will synthesize the costs and benefits for each option to derive net benefits.

In order to calculate the net benefits for a given option and a given demand curve we have to make assumptions in the model concerning the price perceived by the consumer of transits. (Remember from the discussion in Section 5.1 that the quantity of transits consumed is a function of the demand curve and the price.) We assume that the price perceived by the consumer is the economically efficient price, i.e. the y-coordinate of the intersection between the marginal cost curve and the demand curve. The marginal cost curve and the demand curve are lines based on linear regressions on the data sets. There are two different reasons why this is a good assumption to make in the model.

102 See Section 2.2 for why this is the efficient price.
Firstly, the assumption is sufficiently realistic in the absence of tolls. The consumer of transits perceives the major part of the marginal costs: fuel; time costs; safety costs; wear and tear of the car, truck or bus on both the direct route and the indirect route in the case of congestion; maintenance costs of the road are, arguably, passed on through the gasoline tax; operation and maintenance cost of a shuttle service could and should be charged to the user appropriately.

The marginal cost curve can be transformed into a level-of-service (LOS) curve from the transportation systems analysis perspective. The LOS variables that we consider, then, are out of pocket costs, time costs and safety costs. The relationship between the marginal cost curve and the LOS curve, then, is this: The higher the marginal cost the lower is the LOS for that transit. As in our model the quantity of transits is a function of the marginal cost curve, it follows that we include the transportation systems phenomenon that quantity of transits is a function of LOS.

Secondly, with this assumption in place we can give a lower bound on when investment might make sense economically, as the assumption constitutes an idealization from the economic perspective.

Based on the assumption we, then, calculate net benefits for each option as a function of demand equivalents in the following way (Consider Figure 6.9-1): (1) We determine the quantity of transits for a given demand equivalent and marginal cost curve (i.e. technological option) as the x-coordinate of the intersection of the demand curve and the marginal cost curve (Point C in Figure 6.9-1); (2) We calculate gross benefits as the area under the demand curve up to the quantity of transits (Area A-C-D-E in Figure 6.9-1); (3) We calculate total costs for that quantity of transits by multiplying average total costs for that quantity of transits (as determined in Chapter 4) with the quantity of transits (Area

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103 An important LOS variable that we do not consider is the reliability of the transportation link in the different technological options. For instance, the New Road Option is more reliable than the Status Quo Option as travel time is known with a higher degree of certainty due to possible congestion or closure during the winter in the latter. Reliability ought to be included in the next step of the analysis.
FIGURE 6.9-1: CALCULATING NET BENEFITS

$\$/transit
average total cost ($q'$)
price ($q'$)
marginal cost
average total cost
demand
transits/year

A
B
C
D
E

q'

117
F-B-D-E in Figure 6.9-1); (4) We subtract total costs from gross benefits to obtain net benefits (as a function of demand equivalents and technological option).

The comparison of net benefits of the options as a function of demand equivalents is displayed diagramatically in Appendix 6.8-2. In order to compare the net benefits of the investment options to the status quo option, the base case, as a function of demand equivalents we subtract the latter from the former, to obtain relative net benefits for each investment option. The calculations are displayed in Appendix 6.9-1. The results are displayed in Figure 6.9-2.

Figure 6.9-2, in conjunction with Figure 5.2-2, correlating demand equivalents and time, contains the main conclusion of our model:

Figure 6.9-2 indicates that up to a demand per year described by a demand equivalent of approximately 1,400,000, the net benefits per year of the Status Quo Option are larger than for any of the five investment options. Over the demand range from 1,400,000 to 2,000,000 demand equivalents the Alternative Shuttle Option dominates all other options. For demand greater than 2,000,000 demand equivalents the Transandino Alternative Shuttle Option dominates all other options. Thus, according to the model, the only three options that need to be considered further are the Status Quo Option, the Alternative Shuttle Option and the Transandino Alternative Shuttle Option. These are highlighted accordingly in Figure 6.9-2. The New Road Option, Rail Shuttle Option and Transandino Rail Option have less net benefits over the entire range of demand.

How, then, on the basis of the model do we decide between the two non-dominated investment options: The Alternative Shuttle Option and the Transandino Alternative Shuttle Option? As discussed in Section 2.3, it is conceptually required to derive the net present value by setting up a cash flow table on the basis of demand projections for, say, the next 50 years and factor in the effects of each investment option on the benefits and costs of the subsequent investment.
FIGURE 6.9-2: COMPARISON NET BENEFITS RELATIVE TO STATUS QUO

TRANSENDINO ALTERNATIVE SHUTTLE OPTION

ALTERNATIVE SHUTTLE OPTION

STATUS QUO OPTION

$year

-800000000
-600000000
-400000000
-200000000
0
200000000
400000000
600000000
800000000
1000000000

demand curve equivalents

- new road option
- alternative shuttle option
- transandino rail option
- transandino alternative s option
In our case the correct decision between the two options is clear by inspection: At the modest demand growth rate of 5% per year the Alternative Shuttle Option would dominate the Transandino Alternative Shuttle Option for only seven years, the period of time for demand to grow from 1,400,000 to 2,000,000 at 5% per year. It is then plausible to claim that the net present value of operating the link up to 1,600,000 demand equivalents in the Status Quo Option and then implementing the Transandino Alternative Shuttle Option is larger than operating the link up to 1,400,000 demand equivalents in the Status Quo Option and then implementing the Alternative Shuttle Option. Furthermore, considering subsequent investments, the Transandino Alternative Shuttle Option seems at least on par.

Thus, we have determined which of the five investment options considered is optimal according to the model: The Transandino Alternative Shuttle Option. That leaves the question of timing: When is it optimal to start digging the tunnel? Theoretically, as implementing the option is expected to take 11 years, the answer is 11 years before the demand curve described by the demand equivalent of 1,600,000 occurs, as from then on (demand is monotonically increasing through time) the Transandino Alternative Shuttle Option dominates the Status Quo Option. In the terminology of Section 2.3, then, 1,600,000 is the critical demand. Clearly, this only shifts the question to when that is expected to occur. In order to answer this question we have to forecast demand.

Assuming the low estimate of annual future growth of the E.F. of 3% it implies that the critical demand is to occur in the year 2040, and construction thus ought to start in the year 2029 (by which time new technological options will have certainly appeared).

Assuming the medium estimate of annual future growth of the E.F. of 7% implies that the critical demand is to occur in the year 2019, and construction thus ought to start in the year 2008.

Assuming the high estimate of annual future growth of the E.F. of 12% implies that the critical demand is to occur in 2009, and construction thus ought to start in the year 1998.
Assuming the growth pattern suggested by past trade increases in Mercosur, i.e. 30% per year, implies that critical demand is to occur in 2000, and thus construction ought to have started in 1989.

Assuming the growth pattern suggested by the Mercosur - European Community analogy, i.e. 15% per year until 2005 and thereafter 7%, implies that critical demand is to occur in 2007, and thus construction should start in 1996, i.e this year.

So, while the optimal technological choice is largely independent of our expectations of future demand, the timing choice is not.

In circumstances when one is not sure about ones expectations of future states of affairs, it is often helpful to conduct a critical value analysis. The model calculates that for it to be optimal to start construction in 1996 growth rates of demand for at least 13.5% per year for the next 11 years have to occur. Is that a plausible expectation? We see that the available evidence is ambivalent: The analogy with the European Community and past trade figures in Mercosur suggest it to be plausible while the predictions of the E.F. indicate the contrary (if this were not the case the critical value analysis would not be of additional help, anyway). Thus, the critical value analysis does not provide additional insights that would facilitate decision making.

It seems that the only option left apart from more careful demand forecasting is to assign a probability distribution to the different scenarios based on the relative confidence in each of their justifications. This approach is greatly simplified in our framework of analysis on a per year basis as compared to setting up a cashflow table: to make a decision we only need to predict growth rates for 11 years into the future. Let us go through the reasoning for this year, 1996, for a simple expected value analysis. The reasoning is then readily applicable to subsequent years.

In the end of 1996 we have to make the choice between (A) deferring the decision for another year or (B) starting construction so that the Transandino Alternative Shuttle
Option is operational in the beginning of year 2008. Suppose, for reasons of exposition, that based on the evidence we believe there to be a 50% chance of a growth rate of 13.5% for the next 11 years and a 50% chance of a growth rate of 7%. As demand is expected to increase monotonically through time we only need consider the expected value for the year 2008, since if the Transandino Alternative Shuttle Option is expected to dominate in 2008 it will also be expected to dominate thereafter and if it is expected to not dominate the decision is simply deferred to next year (when the decision to build would operationalize the Transandino Alternative Shuttle Option in 2009). Given that the growth rate is 13.5%, the demand equivalent in year 2008 is 1,816,000 for which the model predicts (see Figure 6.9) additional benefits valued at approximately $100 million if the Transandino Alternative Shuttle Option is in place rather than the Status Quo Option.

On the other side, given that the growth rate is only 7%, which translates into a demand equivalent of about 400,000 in the year 2008, approximately $400 million are destroyed by operating in the Transandino Alternative Shuttle Option rather than the Status Quo Option. Thus, we expect a 50% chance of gains of $100 million and a 50% chance of losses of $400 million if we chose to start construction in 1996 rather than delay the decision for a year. As the expected value is $-150 million we would be advised to delay the decision for a year. In the following year the same analysis can then be conducted taking into consideration improvements in demand forecasts and in the technological options available.

Let us now generalize the expected value analysis from discrete probability distributions over states of affairs to continuous probability distributions: For the purpose of illustration, we think through the implications of the expectation, not implausible, that the probability is normally distributed skewed by -0.50 between 3% and 30%. This expectation on future growth is described graphically in Appendix 6.9-2. To do this we apply a method called

\[104\] Note that we assume that construction, once started, is not slowed or in any other way altered. This is not so implausible assumption considering the “self-dynamic” projects feature even at the planning stage.
Monte-Carlo Analysis: The project is realized 500 times. In each realization a random number is generated and mapped - on the basis of the expected probability distribution to a particular growth rate for the next 11 years, on the basis of which the net benefit of the Transandino Alternative Shuttle Option relative to the Status Quo Option in the year 2008 is calculated. The equation of net benefits in year 2008 as a function of growth rate is derived by linear regression analysis in Appendix 6.9-3. The Monte-Carlo analysis estimates the probability distribution of these relative net benefits as a function of the probability distribution of future growth.

Before we discuss the results of this analysis, note that any set of parameters could be used, for instance cost of tunnel construction and economic opportunity cost of capital. However, in our case the best expectation for these parameters is deterministic. And as we argued in Section 4.1 the project ought to be optimized with respect to expected values alone, i.e. we assume that risk is not a cost factor, which implies that considering possible variance in these parameters is not warranted.

The situation is different in the case that variance is a cost factor, or, in other words, in the case that the decision maker is risk averse: Then, as some variance is to be expected, it is advisable to indicate a band of confidence, so that the cost due to risk can be calculated.

We suppose, for the purpose of illustration, that the decision maker's expectations with respect to demand are best described by a normal distribution skewed between 3% and 30%. The expected net benefits for this expectation of the Transandino Alternative Shuttle Option in the year 2008 relative to the status quo option is $-20 million and hence the construction should not start by the end of this year. The result is displayed in Appendix 6.9-4. For the statistically interested, or for those that are not convinced by my case for risk neutrality in the evaluation of the project, some statistical data is displayed.

---

105 In our model we use “Risk Master for Windows”; For a thorough explanation of Monte-Carlo Analysis see S. Savvides “Risk Analysis in Investment Appraisal” Project Appraisal, Volume 9, Number 1, pages 3-18, March 1994; For the probability theory underlying the discussion any textbook will do, for instance see Miller & Freund’s “Probability & Statistics For Engineers” Fifth Edition, Prentice Hall.

106 For simplicity we assume constant growth rates until 2007.
numerically in Appendix 6.9-4 and diagrammatically in Appendix 6.9-5 and Appendix 6.9-6.

The question, though, remains whether one ought to expect a normal distribution -0.5 skewed between 3% and 30%. And that is the crucial question - we have developed an analytic apparatus to, then, derive a justified decision. Note that talk about expectations is here not confined to expectations about future demands but comprises, literally, any assumption made in the model.

Let us consider, again, the choice among technological options. From the expectation perspective a problem for our treatment of risk appears to arise: Our expectations regarding the cost structure of a rail option are of higher quality than those of an alternative shuttle option as many rail tunnels but no alternative shuttle tunnel have been built and operated. In other words there is a lower variance of our expected rail costs as compared to our expected alternative shuttle cost. We have argued in Section 1.4 for risk neutrality with respect to deciding between the two options. It follows that the alternative shuttle option should be chosen, as variance, then, is not an additional cost.

This conclusion, however, is prima facie at odds with the common sense principle that “if I do not have much of an idea what is going to happen implementing an alternative shuttle option I rather choose the rail option”. Clearly, the common sense principle is reasonable. So, if the common sense principle is at odds with our decision principle then this is a strong argument against our decision principle. But is the antecedent true? I believe not: I would rather say that the common sense principle says something about making a decision between an option for which reasonable expectations exist and an option for which reasonable expectations do not exist while our decision principle assumes that there are reasonable expectations for both options. This line of reasoning would solve the apparent tension between the two principles and leave our treatment of risk intact. Unfortunately, a neat criterion for deciding which expectations are reasonable and which are not does not suggest itself.
In this light, then, it is arguable whether there are reasonable expectations about the alternative shuttle options at all. Einstein (MIT) seriously questions the cost assumptions of the alternative shuttle options in the model. It follows that the conclusion of the model that the Transandino Alternative Shuttle Option is the optimal technological choice ought to be questioned. Note, however, that if the expectations are deemed reasonable and a decision had to be made on the available information then the Transandino Alternative Shuttle Option is the technology of choice.

6.10 SENSITIVITY ANALYSIS

In the preceding section we have focussed on the implications of different demand scenarios with respect to which technology and which timing of investment is optimal. We have found that some of our other assumptions also might not qualify for the category of reasonable expectations, which is required if one is to choose timing and technology on expected values alone and ignore other scenarios. In this section we investigate into assumptions in the model that satisfy the following two conditions:

1. It is arguable that the assumption is a reasonable expectation;

2. A plausible change in the assumption implies that a different technological option or (substantially) different timing is optimal (and so makes the latter likely).

We proceed by changing one assumption at a time keeping the remaining assumptions constant. We determine the values for which the optimal technology changes, the critical values, if they exist. The impacts of changes in the assumptions on timing is less revealing as we have no firm expectation on the development of future demand curves and is therefore only considered in particular cases.
The findings in this section ought to be interpreted as signals indicating the assumptions that need to be questioned and further researched, i.e. assumptions satisfying conditions 1 and 2 have a high priority for further research.

6.10.1 DISCOUNT RATE

The discount rate used appears to be well researched and corroborated by an independent feasibility study. So condition 1 is not satisfied. Irrespectively, we proceed with a sensitivity analysis as the effects of small changes in discount rates tend to be extraordinarily large.

The choice among technological options is fairly robust with respect to changes in discount rate: The optimal choice changes from the Transandino Alternative Shuttle Option to the Transandino Alternative Shuttle Option at a discount rate of approximately 15%. Reducing the discount rate has no impact on the optimality of the Transandino Alternative Shuttle Option. Interestingly, although unsuprisingly, the difference of net benefits among the traditional options decreases with decreasing discount rate. The ordering, though, does only change for an unreasonable discount rate of 4% (Transandino Rail Option, New Road Option, Train Shuttle Option).

Optimal timing is positively correlated with the discount rate: The higher the discount rate the later should an investment option be implemented. The impacts of changes in the discount rate, though, are not warranting a detailed quantitative exposition.

We conclude that more research into the correct opportunity cost of capital, the discount rate, has a low priority.
6.10.2 CAPACITY OF STATUS QUO OPTION

As remarked in Section 4.2.3 there is evidence at odds with our assumption that the Status Quo Option has a capacity of 5000 vehicles per day. Thus, it satisfies condition 1. What about condition 2?

The ordering of technological options is invariant to changes in capacity of the Status Quo Option.

Timing on the other hand is significantly affected by changes in capacity. Assuming a capacity of 2000 vehicles per day and a modest growth rate of demand (in demand equivalents) for the next 15 years of 7% implies that it is optimal to start construction for the Transandino Alternative Shuttle Option in the year 2000 as compared to in the year 2009 at a capacity of 5000 vehicles per day. Considering the decision processes involved this means that the project should be seriously pursued as of now. A proper investigation into the capacity of the present link is, particularly considering the low costs of doing so, clearly indicated. On the high side, assuming a capacity of 8000, implies a critical demand equivalent of 2 million versus 1.6 million. The impact on timing is limited as the difference constitutes an increase in demand equivalents of only 25%.

We conclude that more research into the capacity of the Status Quo Option is warranted.

6.10.3 VARIABLE COSTS OF ALTERNATIVE SHUTTLE OPTIONS

As pointed out in Section 5.4.3 the costs of operation (mainly transportation park), maintenance and safety but excluding time in the Alternative Shuttle Option appears to be rather low at 5$ per transit for the shuttle portion of the transit (Prof. H. Einstein, MIT). The same applies, consequently, to the Transandino Alternative Shuttle Option. We compare $5 in the Alternative Shuttle Option to $21 in the same category for the Train
Shuttle Option and $46 in the Transandino Alternative Shuttle Option to $202 in the Transandino Rail Option. So condition 1 is satisfied.

We find that the Train Shuttle Option dominates the Transandino Alternative Shuttle Option if the latter had a cost of $110, which is still a remarkably low 54% of the comparable cost of the Transandino Rail Option. The Alternative Shuttle Option dominates both options. So the optimal choice changes if the assumption is modified to a plausible $110. This alone suffices to motivate further research into the operating costs of the alternative shuttle options.

We find that the Train Shuttle Option dominates the Alternative Shuttle Option if the latter had a cost of $45, which is 214% of the comparable cost of the Train Shuttle Option.

Changes of optimal timing follow from the relative positions of the alternative shuttle options to the Train Shuttle Option. The changes are substantial.

We conclude that research into operating costs and the costs of the transportation park have a high priority for decision making.

6.10.4 OTHER TECHNOLOGICAL OPTIONS

In order to derive from the analysis conducted that the Transandino Alternative Shuttle Option is the optimal option it has to be assumed that the technological options considered are the best available. It is, however, arguable that this assumption is reasonable. So condition 1 is satisfied. A plausible change of the assumption would be to say that it is likely "that the technological options considered are not the best available". It follows, conceptually, that it is likely that a different technological option (precisely the new one) or different timing is optimal. So condition 2 is satisfied and, hence, searching for new, innovative, technological options has a high priority.
The crucial assumption in the above argument leading to the conclusion that considerable effort should be expended on the search for new, innovative solutions is that it is plausible that better technological options could be found. I will argue for this assumption by offering two ideas that are to be expected to lead to an improvement. Prof. H. Einstein (MIT) claims that a gradient of 5% for the rail tunnel is very likely to be suboptimal. Tunnels in Switzerland have a maximum of 2.5%. Secondly, and more generally, it is not to be expected that the process employed in E.F. "First determine the technological parameters of road, rail and alternative shuttle options by an engineering company and then conduct the economic evaluation (no iteration)" leads to an optimal technological choice from the economic perspective. It is to be expected that an iterative process yields a better result. The latter was referred to in Section 1.1 as a dynamic approach to project evaluation and juxtaposed to the former as the static approach to project evaluation. The design and evaluation process of the tunnel project is to be regarded in the phase where the findings of the economic evaluation ought to be used to create new technological options. The model here developed may serve as a feedback for the engineering side.

We conclude that research into new technological options is a high priority.
CHAPTER 7: DISCUSSION OF RESULTS

7.1 SUMMARY OF CHAPTERS 3-6

In Part II of the thesis we have applied the evaluational framework developed in Part I to the Mendoza-Los Andes transportation corridor project. (Part I of the thesis is summarized at the end of Chapter 2)

In Chapter 3 we investigated the potential for benefits of an improvement of the Mendoza-Los Andes transportation corridor. We found strong evidence of the importance of the Mendoza-Los Andes transportation corridor for regional economic development:

Demand is expected to increase as a consequence of the following factors:

1. The Mendoza-Los Andes corridor is the direct terrestrial connection between the economic centres of Buenos Aires/Montevideo on the Atlantic side and Santiago on the Pacific side. (In 1994 all freight and 93.3% of passenger transits between Chile and Argentina used the Mendoza-Los Andes corridor.)

2. As Chile has joined Mercosur, trade barriers are falling and increases in trade between Argentina/Brasil/Uruguay/Paraguay and Chile, and consequently demand for the Mendoza-Los Andes corridor, are to be expected;

3. In the light of global trade liberalization, demand for the Mendoza-Los Andes corridor is expected to further increase as a consequence of increases of the following trade flows: Chile - Brasil, Chile - Europe, Argentina/Brasil/Uruguay/Paraguay - Pacific Rim and bi-oceanic trade (as a substitute of the Panama canal).
There is evidence that the existing transportation link (supply) is inadequate:

1. The Mendoza-Los Andes corridor is unreliable: Historically it has been closed for an average of 30 days during the winter due to severe weather conditions;

2. Congestion occurs during peak periods during the summer;

3. The current safety standard is considered to be too low.

It follows that there is a potential danger for the Mendoza-Los Andes corridor to develop into a transportation bottleneck that has strong and negative implications for regional development. Particular care in the improvement of the corridor is indicated as substantial improvements have been found to require as much as 19 years\(^\text{107}\) for implementation.

In the following chapters, Chapter 4-6, we developed a model of the Mendoza-Los Andes transportation corridor that indicates the optimal technological option and optimal timing for an improvement of the corridor.

We considered six technological options:

1. Status Quo Option - transits\(^\text{108}\) via existing road;

2. New Road Option - transits via low altitude road tunnel;

3. Train Shuttle Option - transits via road to low altitude tunnel and via train shuttle through low altitude tunnel;

4. Alternative Shuttle Option - transits via road to low altitude tunnel and via an alternative shuttle system through low altitude tunnel;

\(^{107}\) See Section 4.3.2.

\(^{108}\) A transit is a trip from Mendoza to Los Andes or vice versa.
5. Transandino Rail Option - transits by train shuttle through low altitude tunnel;

6. Transandino Alternative Shuttle Option - transits by alternative shuttle system through low altitude tunnel.

The model, then, calculates costs and benefits of the operation of one year of the Mendoza-Los Andes Corridor for each of the above technological options for a given demand (or more precisely demand curve). It calculates the net benefits for each technological option as a function of demand: The cost structure of the technological option is determined; Net benefits is, then, the difference between the benefits as determined by the demand curve and total cost as determined by the cost structure, assuming that the link is priced (economically) efficiently.

In order to compare the investment options (options 2-6) to the Status Quo Option, which is the natural base case option, the model calculates net benefits for each technological option relative to the Status Quo by subtracting the former from the latter.

The optimal time to start operating an investment option, then, is the year when the demand curve occurs for which net benefits relative to the Status Quo Option is positive. Construction should start, accordingly, earlier. Such an investment option will be superior to the Status Quo Option from that point in time onwards as demand is to be expected to increase through time.

We choose among investment options by considering which one has the largest net benefits relative to the Status Quo over the demand range (200,000 to 4,000,000 transits per year) considered.

In order to be able to determine the optimal timing of investment the model calculates in which year which demand is to occur based on scenarios of demand development.
These, then, are the optimal technology and the optimal timing of investment as determined by the model:

The optimal technological option is the Transandino Alternative Shuttle Option.

The optimal start for construction is in the year 2029, 2008, 1998, 1989 or 1996 depending on whether the annual growth rate is projected to be, respectively, 3%, 7%, 12%, 30% or 15% until year 2005, then 7%. The results are depicted in Figure 7. In Chapter 5 we found evidence for each of these demand projections. It follows that an unambiguous conclusion with respect to the optimal timing of investment cannot be drawn from the analysis conducted.

We will find, however, in the following, and final, two sections that these results should not be regarded as the main conclusion to draw from the analysis conducted.

7.2 COMPARISON TO RESULTS OF FEASIBILITY STUDY (E.F.)

In this section we compare the methodology and results of the analysis conducted in this thesis to that of the feasibility study commissioned by the Argentinean and Chilean governments (E.F.).

While much of the data used in the thesis is taken from E.F. a substantial difference in the method of analysis exists: In E.F. the benefits of an investment option is defined to be the reduction in transportation costs relative to the status quo. The costs of an investment option are defined as the difference in investment costs, operation costs and maintenance costs between the investment option and the status quo. The benefits and costs are projected to the year 2045, based on three demand scenarios, and the net present value is calculated to determine the optimal technological option. In the thesis, on the other hand, the benefits of all options are defined to be the area under the demand curve, the costs of all options are the respective sums of investment costs, operations costs and maintenance costs and the benefits and costs are compared for one year.
FIGURE 7: OPTIMAL START FOR CONSTRUCTION AS A FUNCTION OF FUTURE ANNUAL TRAFFIC GROWTH RATE
The phenomenon that demand is a function of level of service, which is captured in our model by economic pricing, is incorporated in E.F. by adjusting the demand forecasts to whether the investment option is in place or not so.

E.F. uses an intricate origin-destination model based on perceived travel costs to forecast traffic flows through the Mendoza-Los Andes corridor.

E.F. only considers the New Road Option and the Train Shuttle Option.

The result of E.F. is that the optimal option is the Train Shuttle Option and that construction should begin in the year 2003. With respect to technological choice this result is consistent with the findings of our model. The timing of investment is more difficult to compare as different methods of forecasting are used in both models. However, the “most plausible” future annual growth rate underlying the origin-destination model is in the region of 7%. At a future annual growth rate of 7% our model calculates that construction for the Train Shuttle Option optimally begins in the year 2007. So the two results are remarkably close.

What are the conclusions to draw from this fact?

Generally, conclusions are corroborated if arrived by two conceptually different methods. It follows that the conclusion that it is efficient to begin construction for a rail tunnel between the year 2004 and the year 2007 is justified. This, however, does not imply that the right course of action is to wait until the year 2004 and then start construction. Rather, considering that there are good grounds that construction for an available technological option ought to start in only 8 years, there is an urgency to find better technological options: On the one hand, available technology is indicated to be efficient soon; On the other hand there are good grounds that better technology can be found.

This brings us to the second conclusion to draw from the fact that the results of E.F. and of our model are close.
Generally, the fact that one method yields results that are consistent with another, conceptually not equivalent, method, corroborates the validity of both methods. In particular, it follows that our model is corroborated. Now, we have applied our model to options not considered in the economic feasibility study of E.F. (though presented in E.F.T, i.e. Estudio Factibilidad Tecnologico). We have found that the Train Shuttle Option is dominated by both, the Alternative Shuttle Option and the Transandino Alternative Shuttle Option. As there is now reason to believe that our model is largely plausible, it follows that such, novel, technological options should be further researched.

We conclude that both, the optimal start for construction for the rail tunnel in the year 2004 and the likely availability of superior technology, strongly suggest intensive research into the optimal technological design of the Mendoza-Los Andes transportation corridor.

In the following, final, section we will make suggestions in that regard.

7.3 SUGGESTIONS FOR FURTHER RESEARCH

In our model of the Mendoza-Los Andes transportation corridor we substantially abstracted from reality. We argued that for this stage in the evaluation and design of the project the simplifying assumptions in place are sufficiently realistic. In the course of the discussion and in particular in the sensitivity analysis we noted which assumptions merit particular attention.

We can distinguish between assumptions in the calculation of benefits, assumptions in the calculation of costs and modelling assumptions made to design the overall analytic framework.

On the cost side, the following areas are promising for improving the model:

1. The variable cost assumptions for both alternative shuttle options appear to be too low and, thus, ought to be considered;
2. The assumption on train operation, that supply of locomotives can be increased continuously with demand, should be dropped;

3. The sizable difference between investment costs of a road tunnel ($4.1 billion) and investment costs of a rail tunnel ($1.2 billion) ought to be investigated;

4. Safety costs should not only include costs due to fatalities but also personal injuries and damage to material;

5. The routing of the rail option with a gradient of 5% is likely to be suboptimal (according to Prof. H. Einstein, MIT) and, thus, alternative routes should be investigated;

6. The assumption of risk neutrality of the decision maker should be questioned by determining the appropriate risk attitude;

7. Financial values used should be replaced by economic values (in particular construction costs);

8. Environmental impacts ought to be incorporated;

9. The capacity of the current link should be investigated;

10. A distributive analysis ought to be conducted;

11. Reliability of the link should be included as a cost in the model.

On the benefits side it is strongly indicated to improve the demand forecasts as we have found that small changes in future annual growth rates have a large impact on the optimal timing of an investment. Furthermore, the effects of a rail connection between Mendoza
and Los Andes on demand should be investigated. At the minimum, the actual quantity of transits in the future ought to be observed and analyzed.

We found that the assumptions underlying the analytic framework are well justified. In the face of the current trend of private infrastructure provision, though, it might be warranted to question the assumption of efficient pricing.

The above, then, is a list of suggestions on how to improve the model and the technological options considered.

However, attention should not be limited to these points. Rather, based on our model, a dynamic process between technological design and economic evaluation should take place: New technological options should be designed, evaluated, re-designed, re-evaluated and so forth. One concrete proposal is to investigate the option of combining an alternative shuttle operation with a through rail link, as is done in the Channel tunnel between England and France.

It is suggested that on a yearly basis, the improved expectations with respect to demand and the expectations with respect to the improved technological options should be fed into the improved model to decide whether it is efficient to start construction in that year. This way the investment decision is based on the best information available. The model we have developed is particularly well suited for this process as it determines the demand for which an investment option is efficient, and thus, to make an investment choice, demand only has to be forecasted until the start of operation.

Clearly, this process is not costless. But failure to do so is likely to be costlier considering projected construction periods of 11 years for a rail or shuttle tunnel and of 19 years for a road tunnel and the opportunity costs involved. Drastically put: Once congestion is painful the economically optimal start for the investment is likely to have been missed already.
A final word: We have found that there is good evidence that the low altitude tunnel is a sensible project and that construction should begin in the near future. The Mendoza-Los Andes transportation corridor project has passed the economic sanity check. It is therefore recommended to conduct the design and evaluation process with high intensity.

This project has the potential for substantial development impact in South America, physically linking together the Mercosur nations as never before. We hope this analysis helps guide the way towards deployment of this important infrastructure program.
BIBLIOGRAPHY

K. Arrow, R. Lind “Risk and Uncertainty, in Cost and Benefit Analysis” Cost-Benefit Analysis, CUP.

H. Bohnenblust “Die Risikobeurteilung als Planungshilfe hinsichtlich der Betriebssicherheit von langen Eisenbahntunneln” Sonder Tunnel.


Consorcio Juan Pablo II “Estudio Prefactibilidad Mejoramiento Conexion Internacional Zona Central (Chile) Y La Region Cuyo (Argentina) : Informe Diagnostico Y Propuesta” unpublished.

Consorcio Juan Pablo II “Estudio Prefactibilidad Mejoramiento Conexion Internacional Zona Central (Chile) Y La Region Cuyo (Argentina) : Estudio de Factibilidad Tecnica Tunel a Baje Altura”, unpublished.

Consorcio Juan Pablo II “Estudio Prefactibilidad Mejoramiento Conexion Internacional Zona Central (Chile) Y La Region Cuyo (Argentina) : Estudio de Demanda” unpublished.

Consorcio Juan Pablo II “Estudio Prefactibilidad Mejoramiento Conexion Internacional Zona Central (Chile) Y La Region Cuyo (Argentina) : Evaluacion Economico-Financiera” unpublished.

P. Dasgupta, K. Maeler “The environment and emerging development issues” Cost-Benefit Analysis, CUP

Economist “South America: Getting together” June 1996


M. Jones-Lee “Safety and the savings of life : The economics of safety and physical risk” Cost-Benefit Analysis, CUP.


R. Layard, S. Glaister (ed.) “Cost-Benefit Analysis” CUP.


MVA Consultancy “Time Savings : Research into the value of time” Cost-Benefit Analysis, CUP.


R. Pindyck, D. Rubinfeld “Microeconomics” 3rd edition, Prentice Hall.

S. Rosen “Safety and the savings of life: The theory of equalizing differences” Cost-Benefit Analysis, CUP


E. Stokey, R. Zeckhauser “A Primer for Policy Analysis” Norton.


Dos camiones volcaron

Fuertes vientos causaron accidentes en la montaña

Los vientos arrasaron la zona de alta montaña y de Malargüe; hicieron volcar la carga de dos camiones en Uspallata y en el departamento sureño unas quince viviendas perdieron sus techos. El gobierno municipal ayudará a los damnificados.
### APPENDIX 4.1: GENERAL REMARKS - PARAMETERS APPLICABLE TO ALL OPTIONS

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Discount rate</td>
<td>0.12</td>
</tr>
<tr>
<td>Economic opportunity cost of construction</td>
<td>1 (conversion factor)</td>
</tr>
<tr>
<td>Economic opportunity cost of equipment</td>
<td>1 (conversion factor)</td>
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**Operation cost of average vehicle on road as a function of topography and vehicle type mix**

<table>
<thead>
<tr>
<th>Vehicle type mix (see T.2, E.F.D.63/95/319/914)</th>
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<tr>
<td></td>
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<tr>
<td></td>
<td>0.31</td>
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<table>
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<tr>
<th>Cost of vehicle operation on pavement as a function of topography and vehicle type (incl. time, fuel, maintenance) (E.F.D.303)</th>
<th>$/km</th>
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<tr>
<td>Flat</td>
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<td>Hilly</td>
<td>0.34</td>
</tr>
<tr>
<td>Mountainous</td>
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<tr>
<td>Car</td>
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</tr>
<tr>
<td>Bus</td>
<td>1.83</td>
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<tr>
<td>Truck</td>
<td>1.4</td>
</tr>
<tr>
<td>Average vehicle</td>
<td>1.95</td>
</tr>
</tbody>
</table>

**Cost of road maintenance (per km) 2500 ($/year) (E.F.D.P.353)**

**Cost of snow removal (per km) 2500 ($/year) (E.F.D.P.353)**

**Cost of time as a function of vehicle type (E.F.D.301, estimated from differences in cost per km at different speeds)**

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<thead>
<tr>
<th>Time of day</th>
<th>Car (15)</th>
<th>Bus (120)</th>
<th>Truck (20)</th>
<th>Average (31.25)</th>
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<tr>
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<td>881.988</td>
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<table>
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<tr>
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<table>
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</tr>
<tr>
<td>Average total cost per transit</td>
<td>1,237,363</td>
<td></td>
<td></td>
</tr>
<tr>
<td>distribution of transit (Mr. Boettler, Geoconsult)</td>
<td>1.8 (times average per month = quantity of transits in high transit period)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>high transit: Jan</td>
<td>1.3 (times average per month = quantity of transits in medium transit period)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium transit: Dec, Feb, March</td>
<td>0.8 (times average per month = quantity of transits in low transit period)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assuming: (1) uniform distribution of transits during each transit period

(2) uniform distribution of transits over the day (congestion pricing)

implies

<table>
<thead>
<tr>
<th>Transits per day as a function of transit period and quantity of transit per year</th>
<th>200000</th>
<th>400000</th>
<th>800000</th>
<th>600000</th>
<th>1000000</th>
<th>1200000</th>
<th>1400000</th>
<th>1600000</th>
<th>1800000</th>
<th>2000000</th>
<th>2200000</th>
<th>2400000</th>
<th>2600000</th>
<th>2800000</th>
<th>3000000</th>
<th>3200000</th>
<th>3400000</th>
<th>3600000</th>
<th>3800000</th>
<th>4000000</th>
</tr>
</thead>
<tbody>
<tr>
<td>high transit period</td>
<td>10000</td>
<td>20000</td>
<td>30000</td>
<td>40000</td>
<td>5000</td>
<td>6000</td>
<td>7000</td>
<td>8000</td>
<td>9000</td>
<td>10000</td>
<td>11000</td>
<td>12000</td>
<td>13000</td>
<td>14000</td>
<td>15000</td>
<td>16000</td>
<td>17000</td>
<td>18000</td>
<td>19000</td>
<td>20000</td>
</tr>
<tr>
<td>medium transit period</td>
<td>444444</td>
<td>888888</td>
<td>133333</td>
<td>177777</td>
<td>222222</td>
<td>266666</td>
<td>311111</td>
<td>355555</td>
<td>400000</td>
<td>444444</td>
<td>488888</td>
<td>533333</td>
<td>577777</td>
<td>622222</td>
<td>666666</td>
<td>711111</td>
<td>755555</td>
<td>800000</td>
<td>844444</td>
<td>888888</td>
</tr>
<tr>
<td>low transit period</td>
<td>444444</td>
<td>888888</td>
<td>133333</td>
<td>177777</td>
<td>222222</td>
<td>266666</td>
<td>311111</td>
<td>355555</td>
<td>400000</td>
<td>444444</td>
<td>488888</td>
<td>533333</td>
<td>577777</td>
<td>622222</td>
<td>666666</td>
<td>711111</td>
<td>755555</td>
<td>800000</td>
<td>844444</td>
<td>888888</td>
</tr>
</tbody>
</table>

Cost of safety due to fatalities based on statistical life:

<table>
<thead>
<tr>
<th>Value of statistical life</th>
<th>1000000 ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities/100 mil km</td>
<td></td>
</tr>
<tr>
<td>road (no tunnel)</td>
<td>2.5</td>
</tr>
<tr>
<td>road (tunnel)</td>
<td>2.5</td>
</tr>
<tr>
<td>rail (no tunnel)</td>
<td>0</td>
</tr>
<tr>
<td>rail (tunnel)</td>
<td>0</td>
</tr>
</tbody>
</table>
APPENDIX 4.2.2: STATUS QUO OPTION - FIXED COST
CAPITAL COST

total capital cost 0 ($/year) (See explanation in 2.1)

MAINTENANCE COST

road maintenance (E.F.D.P. 359)

<table>
<thead>
<tr>
<th>km</th>
<th>$0/ln/year</th>
<th>$0/ln/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>241</td>
<td>21000</td>
<td>882500</td>
</tr>
<tr>
<td>100</td>
<td>22500</td>
<td>250000</td>
</tr>
<tr>
<td>total road maintenance</td>
<td>802500</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL FIXED COST 802500

APPENDIX 4.2.3: STATUS QUO OPTION - VARIABLE COST
RELIABLE SERVICE

capacity 5000 (transits per day) (E.F.E. 44)

operations of vehicle

<table>
<thead>
<tr>
<th>km</th>
<th>$0/ln/year</th>
<th>$0/ln/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.4678</td>
<td>9.356</td>
</tr>
<tr>
<td>46</td>
<td>0.6471</td>
<td>29.7696</td>
</tr>
<tr>
<td>195</td>
<td>0.9102</td>
<td>177.469</td>
</tr>
<tr>
<td>cost per transit</td>
<td>216.6116</td>
<td></td>
</tr>
<tr>
<td>cost of safety</td>
<td>6.526</td>
<td></td>
</tr>
</tbody>
</table>

total operation cost per transit 223,1388

UNRELIABLE SERVICE

CONGESTION

global distribution of transit in transits per day as a function of capacity, quantity of transits and distribution of transit through time

transits per year 200000 400000 600000 800000 1000000 1200000 1400000 1600000 1800000 2000000 2200000 2400000 2600000 2800000 3000000 3200000 3400000 3600000 3800000 4000000

low transit period 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

snow

due to snow closed for 15 (days)

quantity of transit re-routed to proximate as a function of capacity and quantity of days

transits per year 200000 400000 600000 800000 1000000 1200000 1400000 1600000 1800000 2000000 2200000 2400000 2600000 2800000 3000000 3200000 3400000 3600000 3800000 4000000

low transit period (transitory) 444,444 888,888 1333,333 | 1777,778 2222,222 2666,667 3111,111 3555,556 4000,000 4444,444 4888,888 5333,333 5777,778 6222,222 6666,667 7111,111 7555,556 8000,000 8444,444 8888,889

snow

due to snow closed for 15 (days)
**EFFECTIVE GEOGRAPHIC DISTRIBUTION OF TRANSITS**

| geographic distribution of transit as a function of quantity of transit and unreliable service | reliable service | unreliable service | per year | 240000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
| passenger mileage | 0.975 | 0.975 | 0.975 | 0.975 | 0.975 | 0.975 | 0.95 | 0.928571 | 0.875 | 0.833333 | 0.8 | 0.777778 | 0.727273 | 0.676923 | 0.625 | 0.578947 | 0.535714 | 0.49375 | 0.454545 | 0.415730 | 0.378378 | 0.34375 |
| passenger miles | 0.025 | 0.046429 | 0.125 | 0.141667 | 0.175 | 0.202273 | 0.245833 | 0.288889 | 0.333333 | 0.361111 | 0.384615 | 0.407407 | 0.425926 | 0.444444 | 0.463636 | 0.483333 | 0.5 | 0.512821 | 0.521739 | 0.53125 |

**TOTAL VARIABLE COST PER TRANSIT**

| 258.8036 | 258.8036 | 258.8036 | 258.8036 | 258.8036 | 267.7676 | 275.4511 | 294.6596 | 308.5997 | 321.5517 | 331.3306 | 357.5145 | 385.2194 | 408.9664 | 429.5471 | 447.5553 | 463.4448 | 477.5669 | 490.0262 | 501.5787 |

**APPENDIX 4.2.4: STATUS QUO OPTION - SYNTHESIS OF COSTS**

**COST PER YEAR**

| transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
| fixed cost per year ($) | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 | 902500 |
| variable cost ($) | 51760722 | 1.06E+08 | 1.56E+08 | 2.07E+08 | 2.59E+08 | 3.11E+08 | 3.66E+08 | 4.21E+08 | 4.77E+08 | 5.37E+08 | 6.00E+08 | 6.66E+08 | 7.38E+08 | 8.14E+08 | 8.95E+08 | 9.80E+08 | 1.06E+08 | 1.15E+08 | 1.24E+08 | 1.34E+08 |
| total cost ($) | 52836222 | 1.06E+08 | 1.56E+08 | 2.07E+08 | 2.59E+08 | 3.11E+08 | 3.66E+08 | 4.21E+08 | 4.77E+08 | 5.37E+08 | 6.00E+08 | 6.66E+08 | 7.38E+08 | 8.14E+08 | 8.95E+08 | 9.80E+08 | 1.06E+08 | 1.15E+08 | 1.24E+08 | 1.34E+08 |

**COST PER TRANSIT**

| transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
| average fixed cost per transit | 4.5125 | 2.25625 | 1.504167 | 1.128125 | 0.9025 | 0.752083 | 0.644444 | 0.564516 | 0.501389 | 0.461290 | 0.410227 | 0.378049 | 0.347115 | 0.323281 | 0.300833 | 0.280331 | 0.260594 | 0.24375 | 0.223009 | 0.212591 | 0.205761 |
| average variable cost per transit | 258.8036 | 258.8036 | 258.8036 | 258.8036 | 258.8036 | 258.8036 | 267.7676 | 275.4511 | 294.6596 | 309.5997 | 321.5517 | 331.3306 | 357.5145 | 385.2194 | 406.9664 | 429.5471 | 447.5553 | 463.4448 | 477.5669 | 490.0262 | 501.5787 |

**Marginal Cost (extra 20000)**

| 258.8036 | 258.8036 | 258.8036 | 258.8036 | 258.8036 | 312.5877 | 321.5517 | 429.1198 | 429.1198 | 429.1198 | 645.3381 | 717.8775 | 717.8775 | 717.8775 | 717.8775 | 717.8775 | 717.8775 | 717.8775 | 717.8775 |

**Linear approximation of marginal cost curve**

| slope | 0.000161 | 162.8881 |
| y-intercept | 522.046 | -2.6E+08 |
APPENDIX 4.3.2: NEW ROAD OPTION - FIXED COST

**CAPITAL COST**

discount rate 0.12

table of cashflows (E.F.T. 281)

| year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| value end of year | 166.7954 | 148.9244 | 132.9682 | 118.7216 | 44.91256 | 40.1005 |
| value of expenditures beginning of operations | 4180.946 (million$) |
| capital cost | 8.02E+08 (S/year) |

**MAINTENANCE COST**

- maintenance of tunnel 2329000 (S/year) (E.F.T. 272)
- road to be maintained 259 2500 647500
- road to be snoopled 70 2500 175000
- road maintenance 822500
- total maintenance cost 3181500 (S/year)

**TOTAL FIXED COST** 5.05E+08 (S/year)

APPENDIX 4.3.3: NEW ROAD OPTION - VARIABLE COST

<p>| cost per transit - operation of vehicle (E.F.T. 190/191) |</p>
<table>
<thead>
<tr>
<th>km</th>
<th>$/year</th>
<th>$/Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat</td>
<td>45</td>
<td>0.4678</td>
</tr>
<tr>
<td>hilly</td>
<td>47</td>
<td>0.6471</td>
</tr>
<tr>
<td>mountainous</td>
<td>167</td>
<td>0.9102</td>
</tr>
<tr>
<td>cost of safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost of environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total operation cost per transit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost of ventilation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL VARIABLE COST</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX 4.3.4: NEW ROAD OPTION - SYNTHESIS OF COSTS

**COST PER TRANSPORT**

| transports per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|---------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| fixed cost per year ($) | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 | 5.05E+08 |
| variable cost ($) | 42050428 | 84100856 | 1.26E+08 | 1.68E+08 | 2.1E+08 | 2.52E+08 | 2.94E+08 | 3.36E+08 | 3.78E+08 | 4.21E+08 | 4.63E+08 | 5.05E+08 | 5.47E+08 | 5.89E+08 | 6.31E+08 | 6.73E+08 | 7.15E+08 | 7.57E+08 | 7.99E+08 | 8.41E+08 |
| total cost ($) | 5.47E+08 | 5.89E+08 | 6.31E+08 | 6.73E+08 | 7.15E+08 | 7.57E+08 | 7.99E+08 | 8.41E+08 | 8.83E+08 | 9.25E+08 | 9.67E+08 | 1.01E+09 | 1.05E+09 | 1.09E+09 | 1.14E+09 | 1.18E+09 | 1.22E+09 | 1.26E+09 | 1.3E+09 | 1.35E+09 |

**COST PER TRANSPORT**

<p>| transports per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|---------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|</p>
<table>
<thead>
<tr>
<th>Linear approximation of marginal cost curve</th>
<th>slope</th>
<th>7.15E-20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y-intercept</td>
<td>210.2521</td>
</tr>
<tr>
<td>Linear approximation of total cost curve</td>
<td>slope</td>
<td>510.2521</td>
</tr>
<tr>
<td></td>
<td>y-intercept</td>
<td>5.05E+06</td>
</tr>
</tbody>
</table>
APPENDIX 4.4.2: TRAIN SHUTTLE OPTION - FIXED COST

CAPITAL COST

discount rate 0.12

table of cashflows (E.F.T.305)

<table>
<thead>
<tr>
<th>year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>value end of year</td>
<td>40.06544</td>
<td>35.77272</td>
<td>25.75002</td>
<td>22.99109</td>
<td>0</td>
<td>148.16</td>
<td>89.23</td>
<td>89.23</td>
<td>143.33</td>
<td>178.94</td>
<td>178.94</td>
</tr>
<tr>
<td>value of expenditures beginning of operations</td>
<td>1210.801 (million $)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>capital cost</td>
<td>1.46E+08 ($/year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MAINTENANCE COST

maintenance of tunnel & rail 419000 ($/year) (E.F.T.272) (only maintenance of installation) fixed - rest: variable

road maintenance (E.F.D.P.190/990)

<table>
<thead>
<tr>
<th>km</th>
<th>$/km/year</th>
<th>$/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>road to be maintained</td>
<td>232</td>
<td>2500</td>
</tr>
<tr>
<td>road to be snowplowed</td>
<td>70</td>
<td>2500</td>
</tr>
<tr>
<td>total road maintenance</td>
<td>302</td>
<td>755000</td>
</tr>
<tr>
<td>total maintenance cost</td>
<td></td>
<td>1174000 ($/year)</td>
</tr>
<tr>
<td>TOTAL FIXED COST</td>
<td>1.46E+08 ($/year)</td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX 4.4.3: TRAIN SHUTTLE OPTION - VARIABLE COST

ROAD PORTION

cost per transit - operation of vehicle (E.F.D.P.190/991)

<table>
<thead>
<tr>
<th>km</th>
<th>$/km</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat</td>
<td>0.4578</td>
<td>8.4204</td>
</tr>
<tr>
<td>hilly</td>
<td>0.6471</td>
<td>30.4137</td>
</tr>
<tr>
<td>mountainous</td>
<td>0.9102</td>
<td>152.0034</td>
</tr>
<tr>
<td>cost of safety</td>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td>cost of environment</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>cost per transit</td>
<td></td>
<td>198.8375</td>
</tr>
</tbody>
</table>

RAIL PORTION

discount rate 0.12 (for calculation of yearly cost of transportation park, tentative)

cost operation, maintenance and safety
(capacity for 10000 vehicles per day)

<table>
<thead>
<tr>
<th>km</th>
<th>$/km/year</th>
<th>$/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>63747800 ($/year)</td>
<td>(E.F.T.305)</td>
<td></td>
</tr>
<tr>
<td>12860000 ($/year)</td>
<td>(E.F.T.272)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>76327800 ($/year)</td>
<td>(for 10000 vehicles per day)</td>
</tr>
<tr>
<td>cost</td>
<td>21.20217 ($/transit)</td>
<td>(divide by 360 * 10000)</td>
</tr>
<tr>
<td>safety</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>subtotal</td>
<td>21.20217 ($/transit)</td>
<td></td>
</tr>
<tr>
<td>cost of time for shuttle</td>
<td></td>
<td>0.5 (hrs.)</td>
</tr>
<tr>
<td>time for loading and unloading on shuttle</td>
<td></td>
<td>(E.F.T.163)</td>
</tr>
<tr>
<td>travel time</td>
<td>0.5 (hrs.)</td>
<td>(E.F.T.162)</td>
</tr>
<tr>
<td>waiting time</td>
<td>0 (hrs.)</td>
<td>(not clear from information)</td>
</tr>
<tr>
<td>total trip time for rail portion</td>
<td>1 (hrs.)</td>
<td></td>
</tr>
<tr>
<td>time cost</td>
<td>31.25 ($/transit)</td>
<td></td>
</tr>
<tr>
<td>total cost - rail portion</td>
<td>52.45217 ($/transit)</td>
<td></td>
</tr>
<tr>
<td>TOTAL VARIABLE COST</td>
<td>248.0897 ($/transit)</td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX 4.4.4: TRAIN SHUTTLE OPTION - SYNTHESIS OF COSTS

### COST PER YEAR

| Transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|-------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Fixed cost per year ($) | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 | 1.46E+08 |
| Variable cost ($) | 49817933 | 99635867 | 1.49E+08 | 1.99E+08 | 2.49E+08 | 2.99E+08 | 3.49E+08 | 3.99E+08 | 4.49E+08 | 4.99E+08 | 5.49E+08 | 5.99E+08 | 6.49E+08 | 6.99E+08 | 7.49E+08 | 7.99E+08 | 8.49E+08 | 8.99E+08 | 9.49E+08 | 9.99E+08 |
| Total cost ($) | 1.96E+08 | 2.46E+08 | 2.96E+08 | 3.46E+08 | 3.96E+08 | 4.46E+08 | 4.96E+08 | 5.46E+08 | 5.96E+08 | 6.46E+08 | 6.96E+08 | 7.46E+08 | 7.96E+08 | 8.46E+08 | 8.96E+08 | 9.46E+08 | 9.96E+08 | 1.04E+09 | 1.09E+09 | 1.14E+09 |

### COST PER TRANSIT

| Transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|-------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Average fixed cost per transit | 732.2304 | 366.1152 | 244.0788 | 183.0576 | 146.4461 | 122.0384 | 104.6043 | 91.5288 | 81.3583 | 73.2230 | 66.5664 | 61.0192 | 56.3254 | 52.3021 | 48.8153 | 45.7644 | 43.0723 | 40.6794 | 38.5244 | 36.6152 |
| Average variable cost per transit | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 |
| Marginal cost (extra 200000) | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 | 249.0897 |

### Linear approximation of marginal cost curve
- **Slope:** 7.18E-20
- **y-intercept:** 249.0897

### Linear approximation of total cost curve
- **Slope:** 249.0897
- **y-intercept:** 1.46E+08
APPENDIX 4.5.2: ALTERNATIVE SHUTTLE OPTION - FIXED COST

CAPITAL COST

discount rate 0.12

table of cashflows (E.F. T.307)

<table>
<thead>
<tr>
<th>year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8.96</td>
<td>8.96</td>
<td>6.46</td>
<td>6.46</td>
<td>0</td>
<td>125.84</td>
<td>83.24</td>
<td>83.23</td>
<td>115.58</td>
<td>154.88</td>
<td>154.88</td>
</tr>
<tr>
<td>value end of year 11</td>
<td>27.8284</td>
<td>24.84679</td>
<td>15.99472</td>
<td>14.281</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

value of expenditures beginning of operations 1025.965 (million $)

capital cost 1.23E+08 ($/year)

MAINTENANCE COST

maintenance of tunnel 47400 ($/year) (E.F. T.272) (only "maintenance of installation" fixed - rest variable)

road maintenance (E.F. DP. 190/395)

<table>
<thead>
<tr>
<th>km</th>
<th>$/km/year</th>
<th>$/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>road to be maintained</td>
<td>232</td>
<td>2500</td>
</tr>
<tr>
<td>road to be snowplowed</td>
<td>70</td>
<td>2500</td>
</tr>
<tr>
<td>total road maintenance</td>
<td>755000</td>
<td></td>
</tr>
<tr>
<td>total maintenance cost</td>
<td>1229000 ($/year)</td>
<td></td>
</tr>
<tr>
<td>TOTAL FIXED COST</td>
<td>1.23E+08 ($/year)</td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX 4.5.3: ALTERNATIVE SHUTTLE OPTION - VARIABLE COST

ROAD PORTION

cost per transit - operation of vehicle (E.F. DP. 190/191)

<table>
<thead>
<tr>
<th>km</th>
<th>$/km</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat</td>
<td>18</td>
<td>0.4678</td>
</tr>
<tr>
<td>hill</td>
<td>47</td>
<td>0.8471</td>
</tr>
<tr>
<td>mountainous</td>
<td>167</td>
<td>0.9102</td>
</tr>
<tr>
<td>cost of safety</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>cost of environment</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>cost per transit</td>
<td>196.6375</td>
<td></td>
</tr>
</tbody>
</table>

SHUTTLE PORTION

discount rate 0.12 (for calculation of yearly cost of transportation park, tentative)

cost operation, maintenance and safety

capital cost & maintenance transportation park 11076000 ($/year) (E.F. T.308) (capital cost per year)

operating cost 6874000 ($/year) (E.F. T.272)

cost 17950000 ($/year)

safety cost 0 ($/transit)

subtotal 4.986667 ($/transit)

cost of time for shuttle

time for loading and unloading on shuttle 0.025 (hrs.) (E.F. T.207)

time for loading and unloading 0.5 (hrs.) (E.F. T.221)

waiting time 0 (hrs.) not clear from information

total trip time for rail portion 0.525 (hrs.)

time cost 16.40625 ($/transit)

TOTAL COST - SHUTTLE PORTION 218.0304 ($/transit)

TOTAL VARIABLE COST 4.986667 ($/transit)
<table>
<thead>
<tr>
<th>COST PER YEAR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transits per year</td>
<td>200000 400000 600000 800000 1000000 1200000 1400000 1600000 1800000 2000000 2200000 2400000 2600000 2800000 3000000 3200000 3400000 3600000 3800000 4000000</td>
</tr>
<tr>
<td>Fixed cost per year ($)</td>
<td>1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08 1.24E+08</td>
</tr>
<tr>
<td>Variable cost ($)</td>
<td>4.36E+08 8.72E+08 1.31E+09 1.74E+09 2.18E+09 2.62E+09 3.06E+09 3.49E+09 3.92E+09 4.36E+09 4.80E+09 5.23E+09 5.66E+09 6.08E+09 6.51E+09 6.94E+09 7.37E+09 7.80E+09 8.22E+09</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>5.60E+09 2.12E+10 2.55E+10 2.99E+10 3.42E+10 3.86E+10 4.30E+10 4.73E+10 5.17E+10 5.60E+10 6.04E+10 6.48E+10 6.91E+10 7.35E+10 7.78E+10 8.22E+10 8.66E+10 9.09E+10 9.53E+10 9.96E+10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COST PER TRANSIT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transits per year</td>
<td>200000 400000 600000 800000 1000000 1200000 1400000 1600000 1800000 2000000 2200000 2400000 2600000 2800000 3000000 3200000 3400000 3600000 3800000 4000000</td>
</tr>
<tr>
<td>Average fixed cost per transit</td>
<td>621.724 310.862 207.214 155.431 124.348 103.820 88.817 77.716 69.080 62.172 56.506 51.810 47.824 44.408 41.440 38.577 36.572 34.502 32.722 31.086</td>
</tr>
</tbody>
</table>

Linear approximation of marginal cost curve:

- Slope: -7.2E-02
- y-intercept: 218.0304

Linear approximation of total cost curve:

- Slope: 218.0304
- y-intercept: 1.24E+08
APPENDIX 4.6.2: THE TRANSANDINO RAIL OPTION - FIXED COST

CAPITAL COST

discount rate 0.12

assumption: Investment in infrastructure as in rail shuttle option + tracks mendocino - punta del inca, juncal - los andes
track same distance as roads, investment spread during last 4 years
cost of track 7000000 (SAm) (herman koene beununternehmung gmbh)

<p>| table of cashflows (E.F.T.305) |</p>
<table>
<thead>
<tr>
<th>year (millions of $)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>expenditures as rail shuttle option</td>
<td>12.9</td>
<td>12.9</td>
<td>10.4</td>
<td>10.4</td>
<td>0</td>
<td>148.16</td>
<td>89.23</td>
<td>89.23</td>
<td>143.33</td>
<td>178.94</td>
<td>178.94</td>
</tr>
<tr>
<td>total expenditure (end of year)</td>
<td>12.9</td>
<td>12.9</td>
<td>10.4</td>
<td>10.4</td>
<td>0</td>
<td>148.16</td>
<td>89.23</td>
<td>89.23</td>
<td>495.23</td>
<td>549.33</td>
<td>584.94</td>
</tr>
<tr>
<td>value end of year 11</td>
<td>40.06544</td>
<td>35.77272</td>
<td>25.75002</td>
<td>22.99109</td>
<td>0</td>
<td>261.1085</td>
<td>140.4051</td>
<td>695.7625</td>
<td>668.0796</td>
<td>655.1328</td>
<td>584.94</td>
</tr>
</tbody>
</table>

value of expenditures beginning of operations 3151.008 (million$)
capital cost 3.78E+08 ($/year)

MAINTENANCE COST

maintenance cost of extra track 10000 (S$m/year)
maintenance of tunnel & rail 4190000 ($/year) (E.F.T.272) (only "maintenance of installation" fixed - rest variable)
maintenance cost of extra tracks 2320000 ($/year)
total maintenance cost 2738000 ($/year)
TOTAL FIXED COST 3.81E+08 ($/year)

APPENDIX 4.6.3: THE TRANSANDINO RAIL OPTION - VARIABLE COST

discount rate 0.12 (for calculation of yearly cost of transportation park, tentative)

assumption: electricity consumption & transportation park pro rate extrapolated from 23 km (rail shuttle option) to 255 km operation (electricity severely overstated - flat vs. mountainous terrain)
cost operation, maintenance and safety
capital cost and maintenance transportation park 6.18E+08 ($/year) (E.F.T.305) (capacity for 10000 vehicles per day)
operating cost 1.12E+08 ($/year) (E.F.T.272) (for 10000 transit per day)
total 7.3E+08 ($/year) (for 10000 vehicles per day)
cost 202.877 ($/transit) (divide by 360 * 10000)
safety cost 0 ($/transit)
subtotal 202.877 ($/transit)
cost of time for shuttle
time for loading and unloading on shuttle 0.5 (hrs.) (E.F.T.183)
travel time 2.53 (hrs.) (255 km at 100 km/hr average)
waiting time 0 (hrs.) (not clear from information)
total trip time for rail portion 3.05 (hrs.)
time cost 95.3125 ($/transit)
TOTAL VARIABLE COST 298.1895 ($/transit)
### APPENDIX 4.6.4: THE TRANSENDINO RAIL OPTION - SYNTHESIS OF COSTS

#### COST PER YEAR

<table>
<thead>
<tr>
<th>Year</th>
<th>Fixed Cost per Year ($)</th>
<th>Variable Cost ($)</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>3.81E+08</td>
<td>5.9637906</td>
<td>5.96E+08</td>
</tr>
<tr>
<td>500</td>
<td>3.81E+08</td>
<td>9.5437906</td>
<td>9.54E+08</td>
</tr>
<tr>
<td>700</td>
<td>3.81E+08</td>
<td>1.3237906</td>
<td>1.32E+08</td>
</tr>
<tr>
<td>900</td>
<td>3.81E+08</td>
<td>1.6937906</td>
<td>1.69E+08</td>
</tr>
</tbody>
</table>

#### COST PER TRANSIT

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Fixed Cost per Transit</th>
<th>Average Variable Cost per Transit</th>
<th>Average Total Cost per Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>190.43</td>
<td>298.1895</td>
<td>488.6195</td>
</tr>
<tr>
<td>500</td>
<td>173.1182</td>
<td>298.1895</td>
<td>471.3077</td>
</tr>
<tr>
<td>700</td>
<td>160.0942</td>
<td>298.1895</td>
<td>425.1428</td>
</tr>
<tr>
<td>900</td>
<td>146.4846</td>
<td>298.1895</td>
<td>403.984</td>
</tr>
</tbody>
</table>

#### Linear Approximation of Marginal Cost Curve

- **Slope:** 0
- **Y-Intercept:** 298.1895

#### Linear Approximation of Total Cost Curve

- **Slope:** 298.1895
- **Y-Intercept:** 3.81E+08
APPENDIX 4.7.2: THE TRANSANDINO ALTERNATIVE SHUTTLE OPTION - FIXED COST

**CAPITAL COST**

| Discount rate | 0.12 |

**Assumption:** Investment in infrastructure as in alternative shuttle option + tracks mendoza - punta del inca, juncaí - los andes. Tracks same distance as roads, investment spread during last 4 years.

**Cost of track:** 7000000 (S$m)

**Capital Cost:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Expenditures end of year (million $)</th>
<th>Total Expenditure (end of year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.96</td>
<td>27.8284</td>
</tr>
<tr>
<td>2</td>
<td>8.96</td>
<td>24.84579</td>
</tr>
<tr>
<td>3</td>
<td>6.46</td>
<td>15.96472</td>
</tr>
<tr>
<td>4</td>
<td>6.46</td>
<td>14.281</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>125.84</td>
<td>125.84</td>
</tr>
<tr>
<td>7</td>
<td>83.24</td>
<td>83.24</td>
</tr>
<tr>
<td>8</td>
<td>83.23</td>
<td>83.23</td>
</tr>
<tr>
<td>9</td>
<td>115.58</td>
<td>115.58</td>
</tr>
<tr>
<td>10</td>
<td>154.88</td>
<td>154.88</td>
</tr>
<tr>
<td>11</td>
<td>154.88</td>
<td>154.88</td>
</tr>
</tbody>
</table>

**Value of expenditures at beginning of operations:** 2960.372 (million$)

**Maintenance Cost**

<table>
<thead>
<tr>
<th>Year</th>
<th>Maintenance cost of extra track</th>
<th>Maintenance cost of extra tracks</th>
<th>Total maintenance cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10000 (S$m)</td>
<td>700000 (S/year)</td>
<td>817000 (S/year)</td>
</tr>
<tr>
<td>2</td>
<td>0 (S/year)</td>
<td>1174000 (S/year)</td>
<td>1174000 (S/year)</td>
</tr>
</tbody>
</table>

**Total Fixed Cost:** 3.87E+08 (S/year)

**APPENDIX 4.7.3: THE TRANSANDINO ALTERNATIVE SHUTTLE OPTION - VARIABLE COST**

**Discount rate:** 0.12 (for calculation of yearly type cost of transportation per ton-mile)

**Assumption:** Electricity consumption & transportation park per mile extrapolated from 23 km (rail shuttle option) to 255 km operation (electricity severity overstated - flat vs. mountainous terrain).

**Cost of fuel, maintenance and safety**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost of fuel, maintenance and safety</th>
<th>1.06E+08 (S/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(E.F.T.305) (capacity for 10000 vehicles per day)</td>
<td>57569957 (S/year)</td>
</tr>
<tr>
<td>2</td>
<td>(E.F.T.272 for 10000 travel per day)</td>
<td>166E+08 (S/year)</td>
</tr>
<tr>
<td>3</td>
<td>(capacity for 10000 vehicles per day)</td>
<td>46 1078 (S/tranlit)</td>
</tr>
<tr>
<td>4</td>
<td>(capacity for 360 10000)</td>
<td>46 1078 (S/tranlit)</td>
</tr>
</tbody>
</table>

**Cost of time for shuttle**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost of time for shuttle</th>
<th>0.025 (hrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(E.F.T.207)</td>
<td>2.55 (hrs.)</td>
</tr>
<tr>
<td>2</td>
<td>(255 km at 100 km/hr average)</td>
<td>0 (hrs.)</td>
</tr>
<tr>
<td>3</td>
<td>(not clear from information)</td>
<td>2.575 (hrs.)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>80 48575 (S/tranlit)</td>
</tr>
</tbody>
</table>

**Total Variable Cost:** 126.9767 (S/tranlit)
## APPENDIX 4.7.A : THE TRANSANDINO ALTERNATIVE SHUTTLE OPTION - SYNTHESIS OF COSTS

### COST PER YEAR

| Transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|-------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Fixed cost per year ($) | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 | 3.57E+08 |
| Variable cost per year ($) | 25315348 | 50630692 | 75946038 | 1.01E+08 | 1.27E+08 | 1.52E+08 | 1.77E+08 | 2.03E+08 | 2.29E+08 | 2.53E+08 | 2.78E+08 | 3.04E+08 | 3.30E+08 | 3.55E+08 | 3.81E+08 | 4.06E+08 | 4.31E+08 | 4.56E+08 | 4.81E+08 | 5.06E+08 |
| Total cost per year ($) | 3.82E+08 | 4.05E+08 | 4.23E+08 | 4.43E+08 | 4.63E+08 | 4.84E+08 | 5.06E+08 | 5.29E+08 | 5.53E+08 | 5.78E+08 | 6.05E+08 | 6.33E+08 | 6.61E+08 | 6.90E+08 | 7.20E+08 | 7.50E+08 | 7.81E+08 | 8.11E+08 | 8.42E+08 | 8.73E+08 |

### COST PER TRANSIT

| Transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|-------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Average fixed cost per transit ($) | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 | 1756.693 |
| Average variable cost per transit ($) | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 | 1017.41 |
| Marginal cost (extra 200000) ($) | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 | 126.5767 |

### Linear approximation of marginal cost curve

- **Slope**: -3.6E-08
- **y-intercept**: 126.5767

### Linear approximation of total cost curve

- **Slope**: 3.57E+08
## APPENDIX 4B: COMPARISON OF AVERAGE TOTAL COSTS

Average total cost per option as a function of quantity of transits ($/transit)

| Transits per year | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|-------------------|-------|-------|-------|-------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Status quo option | 262.3161 | 261.0599 | 260.3078 | 259.6317 | 259.1061 | 268.5127 | 276.0957 | 295.2237 | 310.121 | 322.0029 | 331.7408 | 357.8066 | 385.5665 | 400.2867 | 429.848 | 447.8373 | 463.7103 | 477.8196 | 507.7054 |
| Alternative shuttle option | 639.7544 | 528.8924 | 425.2718 | 373.4614 | 342.3752 | 321.6511 | 306.8481 | 295.7459 | 287.1109 | 280.2326 | 274.5508 | 269.8408 | 265.8553 | 262.4393 | 259.4787 | 256.8882 | 254.6024 | 252.7067 | 249.1166 |
| Transandino alt. sh. option | 1912.27 | 1019.423 | 721.8078 | 573.0001 | 483.7154 | 424.1923 | 381.6758 | 349.7884 | 324.9871 | 305.1461 | 288.9125 | 275.3845 | 263.9378 | 254.1263 | 245.623 | 238.1826 | 231.6175 | 225.7819 | 220.5606 | 215.8614 |
APPENDIX 5.2-1: SHAPE OF DEMAND CURVE

SHAPE OF DEMAND CURVE (E.F.D.305-332XHÍPOTESIS MEDIA, YEAR 2010)

cars (E.F.D.310)

<table>
<thead>
<tr>
<th>perceived operating cost</th>
<th>0.35 ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>operations ($/car)</td>
<td>90.65 90.65 90.65 90.65 90.65 90.65 90.65 90.65 90.65 90.65</td>
</tr>
<tr>
<td>tot ($/car)</td>
<td>0 20 40 60 80 120 150</td>
</tr>
<tr>
<td>total ($/car)</td>
<td>90.65 110.65 130.65 150.65 170.65 210.65 240.65</td>
</tr>
<tr>
<td>quantity of car transits</td>
<td>470573 456256 437173 412368 380899 300073 233871</td>
</tr>
</tbody>
</table>

buses (E.F.D.314)

<table>
<thead>
<tr>
<th>perceived operating cost</th>
<th>1.225 ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tot ($/bus)</td>
<td>0 100 150 200 300 400 600 800 1000</td>
</tr>
<tr>
<td>total ($/bus)</td>
<td>317.275 417.275 467.275 517.275 617.275 717.275 917.275 1117.275</td>
</tr>
<tr>
<td>quantity of bus transits</td>
<td>97544 92145 88399 83829 72118 57962 31920 16731</td>
</tr>
</tbody>
</table>

trucks (E.F.D.305)

<table>
<thead>
<tr>
<th>perceived operating cost</th>
<th>1.075 ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>operations ($/truck)</td>
<td>278.425 278.425 278.425 278.425 278.425 278.425 278.425</td>
</tr>
<tr>
<td>tot ($/truck)</td>
<td>0 100 150 200 300 400 600 800 1000</td>
</tr>
<tr>
<td>quantity of truck transits</td>
<td>261780 237397 223637 208154 192672 177290 161908 146526 131154</td>
</tr>
</tbody>
</table>

synthesizing demand curves into demand curve of average vehicle (warranted as proportions sufficiently similar)
vehicle type mix (see T.2, E.F.D.830/310/314)

| car | 0.55 |
| bus | 0.14 |
| truck | 0.31 |

average vehicle perceived operating cost 0.69725 ($/km)

| operations | 180.5878 180.5878 180.5878 180.5878 180.5878 180.5878 180.5878 |
| tot ($/vehicle) | 0 56 89 123 179 246 362.5 |
| total ($/vehicle) | 180.5878 238.5878 270.5878 303.5878 359.5878 426.5878 533.0878 |
| quantity of vehicles | 829877 785798 749209 705351 631779 506398 362453 |

linear approximation of representative demand curve
slope -0.00072
y-intercept 797.5621
APPENDIX 5.2-2: CORRELATING TIME AND DEMAND CURVES

DEMAND CURVE PROJECTIONS: YEAR OF ACTUALIZATION OF DEMAND CURVE IN FIVE SCENARIOS

we consider the set of demand curves of the form \( mx + n \) defined by

\[
m = \frac{rb}{-0.00072}
\]

\( n \) such that the x-coordinate of the intersection with \( y = 277 \) is a multiple of 200000 (this way a similar form to "quantity of transit" is usable)

actual traffic at 277 ($) in 1994

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td>295333</td>
<td>304193</td>
<td>325263</td>
<td>336809</td>
<td>473922</td>
<td>549406</td>
<td>636912</td>
<td>738356</td>
<td>855967</td>
<td>992289</td>
<td>1150335</td>
<td>1333553</td>
<td>1545854</td>
</tr>
<tr>
<td>7%</td>
<td>295333</td>
<td>316006</td>
<td>443215</td>
<td>621632</td>
<td>871871</td>
<td>122845</td>
<td>171610</td>
<td>240952</td>
<td>337368</td>
<td>473202</td>
<td>628607</td>
<td>9308806</td>
<td>13055801</td>
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<tr>
<td>12%</td>
<td>295333</td>
<td>330773</td>
<td>562935</td>
<td>1027331</td>
<td>1810008</td>
<td>3190733</td>
<td>5623162</td>
<td>990832</td>
<td>17494696</td>
<td>30778745</td>
<td>54249065</td>
<td>9594110</td>
<td>1680708</td>
</tr>
<tr>
<td>16% - 7%</td>
<td>295333</td>
<td>338833</td>
<td>683123</td>
<td>1374005</td>
<td>1927113</td>
<td>3702875</td>
<td>7390222</td>
<td>1531686</td>
<td>2747138</td>
<td>5056574</td>
<td>9084976</td>
<td>16689673</td>
<td>20549776</td>
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<tr>
<td>30%</td>
<td>295333</td>
<td>383932</td>
<td>1425516</td>
<td>5292841</td>
<td>19651948</td>
<td>72966309</td>
<td>2.37E+08</td>
<td>3.73E+08</td>
<td>4.73E+09</td>
<td>5.83E+10</td>
<td>1.91E+11</td>
<td>7.1E+11</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX 5.2-3: CORRELATING CHILE - ARGENTINA TRADE AND TRANSTS IN THE MENDOZA - LOS ANDES CORRIDOR

<table>
<thead>
<tr>
<th>Year</th>
<th>Absolute Values</th>
<th>Trade Value (mUS$)</th>
<th>Transits</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>574</td>
<td>1991</td>
<td>669</td>
<td>0.513937</td>
</tr>
<tr>
<td>1991</td>
<td>697</td>
<td>1992</td>
<td>1227</td>
<td>0.411968</td>
</tr>
<tr>
<td>1992</td>
<td>1298</td>
<td>1993</td>
<td>1298</td>
<td>0.057865</td>
</tr>
<tr>
<td>1993</td>
<td>966</td>
<td>1994</td>
<td>223781</td>
<td>-0.25578</td>
</tr>
</tbody>
</table>

Note: data consistent with E.F.DP.33 for imports + exports (Chilean perspective).

Note: data inconsistent with E.F.DP.193 (Chilean perspective).

Trade Value: imports + exports (Chilean perspective).

Transits: imports + exports (Argentinean perspective).
APPENDIX 5.2-4: INCREASE IN TRADE VS. INCREASE IN TRANSITS

\[ y = 0.0263x + 0.0621 \]

\[ R^2 = 0.0033 \]
APPENDIX 8 : SYNTHESIS OF BENEFITS AND COSTS - NET BENEFITS

APPENDIX 8.1 : ON CALCULATIONS

we keep the shape of the demand curve constant (i.e.) at mb
-0.00072 (see 3)

family of demand curves defined uniquely by demand equivalents

\[ \text{mb}^* x - \text{mb}^* q = 277 \]  
(q = demand equivalents)

then, gross benefits is defined to be the area between the mb curve and the x - axis between 0 and the coordinate of the point of intersection of mc and mb.

we shift the demand curve x.t at mc = 277 (fixedprice) the intersections of mb curves and mc = 277 are 200000 (transits) apart.

then solve mb(q) + mb(q) for q for each option with each demand curve

then gross benefits as a function of a given demand curve is

\[ gb(q) = 0.5 \text{mb}^*q^2 - \text{mb}^*q + 277q \]  
(determination fairly straightforward)

APPENDIX 8.2 : STATUS QUO OPTION - NET BENEFITS

linear approximation of marginal cost curve

slope 0.000151
y-intercept 162881

linear approximation of total cost curve

slope 522.046
y-intercept -2.6E+08

definition of mb curves

mb = mc at quantity =

<table>
<thead>
<tr>
<th>Quantity</th>
<th>200000</th>
<th>400000</th>
<th>800000</th>
<th>1200000</th>
<th>1600000</th>
<th>2000000</th>
<th>2200000</th>
<th>2400000</th>
<th>2600000</th>
<th>2800000</th>
<th>3000000</th>
<th>3200000</th>
<th>3400000</th>
<th>3600000</th>
<th>3800000</th>
</tr>
</thead>
<tbody>
<tr>
<td>mc</td>
<td>32945.8</td>
<td>369322.1</td>
<td>369322.1</td>
<td>32945.8</td>
<td>208886.0</td>
<td>201321.1</td>
<td>193756.2</td>
<td>186191.3</td>
<td>178626.4</td>
<td>171061.5</td>
<td>163496.6</td>
<td>155931.7</td>
<td>148366.8</td>
<td>140801.9</td>
<td></td>
</tr>
<tr>
<td>gross benefits ($)</td>
<td>92490084.4</td>
<td>83615580.8</td>
<td>83615580.8</td>
<td>92490084.4</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
<td>62740051.2</td>
</tr>
<tr>
<td>total cost ($)</td>
<td>1.96E+08</td>
<td>2.37E+08</td>
<td>2.37E+08</td>
<td>1.96E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
</tr>
<tr>
<td>net benefits ($)</td>
<td>1.96E+08</td>
<td>2.37E+08</td>
<td>2.37E+08</td>
<td>1.96E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
<td>1.22E+08</td>
</tr>
</tbody>
</table>

APPENDIX 8.3 : NEW ROAD OPTION - NET BENEFITS

linear approximation of marginal cost curve

slope 7.18E-20
y-intercept 2102521

linear approximation of total cost curve

slope 2102521
y-intercept 5.05E-08

definition of mb curves

mb = mc at quantity =

| Quantity | 200000 | 400000 | 800000 | 1200000 | 1600000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|----------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| mc       | 2093221 | 2493221 | 2893221 | 3293221 | 3693221 | 3993221 | 4393221 | 4793221 | 5193221 | 5593221 | 5993221 | 6393221 | 6793221 | 7193221 | 7593221 |
| gross benefits ($) | 92434114.1 | 83615580.8 | 83615580.8 | 92434114.1 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 | 62740051.2 |
| total cost ($) | 5.67E+08 | 6.09E+08 | 6.51E+08 | 6.93E+08 | 7.35E+08 | 7.77E+08 | 8.19E+08 | 8.61E+08 | 9.03E+08 | 9.45E+08 | 9.87E+08 | 1.03E+08 | 1.07E+08 | 1.11E+08 | 1.16E+08 |
| net benefits ($) | -4.7E+08 | -4.2E+08 | -3.7E+08 | -2.5E+08 | -1.7E+08 | -0.9E+08 | -0.1E+08 | 0.8E+08 | 1.6E+08 | 2.4E+08 | 3.2E+08 | 4.0E+08 | 4.8E+08 | 5.6E+08 | 6.4E+08 | 7.2E+08 | 8.0E+08 |
APPENDIX 6.4: TRAIN SHUTTLE OPTION
inner approximation of marginal cost curve
slope 7.18E-20
y-intercept 249.0897
inner approximation of total cost curve
slope 249.0897
y-intercept 1.46E+08
definition of mb curves
mb = mc at quantity =
gross benefit ($) 759738.2 1.76E+08 3.06E+08 4.61E+08 6.45E+08 8.56E+08 1.16E+09 1.37E+09 1.87E+09 2.2E+09 2.35E+09 2.74E+09 3.15E+09 3.59E+09 4.06E+09 4.59E+09 5.09E+09 5.62E+09 6.23E+09 6.85E+09
total cost ($) 2.06E+08 2.56E+08 3.06E+08 3.56E+08 4.05E+08 4.55E+08 5.05E+08 5.55E+08 6.05E+08 6.54E+08 7.04E+08 7.54E+08 8.04E+08 8.54E+08 9.03E+08 9.53E+08 1.05E+09 1.15E+09
net benefit ($) -1.38E+08 -7.7E+07 -27.27E+06 2.4E+08 4.03E+08 5.95E+08 8.15E+08 1.06E+09 1.34E+09 1.63E+09 1.98E+09 2.35E+09 2.74E+09 3.16E+09 3.61E+09 4.06E+09 4.58E+09 5.13E+09 5.69E+09

APPENDIX 8.8: ALTERNATIVE SHUTTLE OPTION - NET BENEFITS
inner approximation of marginal cost curve
slope 7.2E-20
y-intercept 218.0304
inner approximation of total cost curve
slope 218.0304
y-intercept 1.24E+08
definition of mb curves
mb = mc at quantity =
gross benefit ($) 282357.7 4.82E+07 6.82E+07 8.82E+07 1.08E+08 1.28E+08 1.48E+08 1.68E+08 1.88E+08 2.08E+08 2.28E+08 2.48E+08 2.68E+08 2.88E+08 3.08E+08 3.28E+08 3.48E+08 3.68E+08 3.88E+08 4.08E+08

APPENDIX 8.9: TRANSPORTATION ALTERNATIVE - NET BENEFITS
inner approximation of marginal cost curve
slope 296.1895
y-intercept 296.1895
definition of mb curves
mb = mc at quantity =
gross benefit ($) 170406.4 3.70E+06 4.70E+06 5.70E+06 6.70E+06 7.70E+06 8.70E+06 9.70E+06 1.07E+07 1.17E+07 1.27E+07 1.37E+07 1.47E+07 1.57E+07 1.67E+07 1.77E+07 1.87E+07 1.97E+07 2.07E+07

APPENDIX 8.7: TRANSPORTATION ALTERNATIVE SHUTTLE OPTION - NET BENEFITS
inner approximation of marginal cost curve
slope -3.6E-20
y-intercept 126.5767
definition of mb curves
mb = mc at quantity =
gross benefit ($) 410068.3 6.10E+03 8.10E+03 1.01E+03 1.21E+03 1.41E+03 1.61E+03 1.81E+03 2.01E+03 2.21E+03 2.41E+03 2.61E+03 2.81E+03 3.01E+03 3.21E+03 3.41E+03 3.61E+03 3.81E+03 4.01E+03

---

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| Definitions of net curves | 200000 | 400000 | 600000 | 800000 | 1000000 | 1200000 | 1400000 | 1600000 | 1800000 | 2000000 | 2200000 | 2400000 | 2600000 | 2800000 | 3000000 | 3200000 | 3400000 | 3600000 | 3800000 | 4000000 |
|--------------------------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Status quo option        | 1.96E+08 | 2.01E+08 | 2.34E+08 | 2.94E+08 | 3.82E+08 | 4.97E+08 | 6.41E+08 | 8.12E+08 | 1.01E+09 | 1.24E+09 | 1.49E+09 | 1.77E+09 | 2.08E+09 | 2.42E+09 | 2.76E+09 | 3.18E+09 | 3.6E+09 | 4.04E+09 | 4.52E+09 | 5.02E+09 |
| New road option          | -4.7E+08 | -4.2E+08 | -3.3E+08 | -2.2E+08 | -1.7E+08 | -1.1E+08 | -0.7E+08 | -0.5E+08 | -0.3E+08 | -0.2E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 |
| Rail shuttle option      | -1.3E+08 | -7.7E+07 | -27.2E+07 | 1.0E+08 | 2.4E+08 | 4.03E+08 | 5.95E+08 | 8.15E+08 | 1.06E+09 | 1.34E+09 | 1.65E+09 | 1.94E+09 | 2.35E+09 | 2.74E+09 | 3.16E+09 | 3.61E+09 | 4.09E+09 | 4.59E+09 | 5.13E+09 | 5.88E+09 |
| Alternative shuttle option| -9.6E+07 | -4.1E+07 | 4.23E+07 | 1.54E+08 | 2.9E+08 | 4.64E+08 | 6.62E+08 | 8.80E+08 | 1.14E+09 | 1.43E+09 | 1.74E+09 | 2.08E+09 | 2.45E+09 | 2.85E+09 | 3.28E+09 | 3.72E+09 | 4.22E+09 | 4.73E+09 | 5.27E+09 | 5.84E+09 |
| Transandino rail option  | -3.7E+08 | -3.3E+08 | -2.6E+08 | -1.7E+08 | -1.4E+08 | -1.1E+08 | -0.9E+08 | -0.7E+08 | -0.6E+08 | -0.5E+08 | -0.4E+08 | -0.3E+08 | -0.2E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 | -0.1E+08 |
| Transandino alternative s option | -3.8E+08 | -2.2E+08 | -1.2E+08 | 8.12E+06 | 1.67E+06 | 3.55E+06 | 5.71E+06 | 8.16E+06 | 1.09E+08 | 1.39E+09 | 1.72E+09 | 2.08E+09 | 2.47E+09 | 2.89E+09 | 3.33E+09 | 3.81E+09 | 4.31E+09 | 4.84E+09 | 5.4E+09 | 5.96E+09 |
APPENDIX 6.8-2: COMPARISON NET BENEFITS

The graph illustrates the comparison of different options in terms of their net benefits. The x-axis represents the demand curve equivalent, while the y-axis shows the net benefits in dollars per year. The options compared include the status quo, new road, rail shuttle, alternative shuttle, Transandino rail, and Transandino alternative s option. Each line on the graph corresponds to a different option, allowing for a visual comparison of their relative benefits across different demand levels.
### APPENDIX 6-1: COMPARISON OF NET BENEFITS RELATIVE TO STATUS QUO OPTION

For each option we subtract from net benefits the net benefits of status quo option (base case).

<table>
<thead>
<tr>
<th>Option</th>
<th>Definition of net curves</th>
<th>Net benefit relative to status quo option ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New road option</td>
<td>-7E*08</td>
<td>-6.2E+08 -5.7E+08 -5.1E+08 -4.6E+08 -4E+08 -3.5E+08 -2.9E+08 -2.3E+08 -1.7E+08</td>
</tr>
<tr>
<td>Train shuttle option</td>
<td>-2E+08</td>
<td>-2.8E+08 -2.3E+08 -1.9E+08 -1.4E+08 -9.4E+07 -4.6E+07 -3.5E+07 5.9E+06</td>
</tr>
<tr>
<td>Alternative shuttle option</td>
<td>-2E+08</td>
<td>-2.8E+08 -2.3E+08 -1.9E+08 -1.4E+08 -8.7E+07 -3.3E+07 2.1E+07 3.3E+06</td>
</tr>
<tr>
<td>Transalpino rail option</td>
<td>-5.7E+08</td>
<td>-5.3E+08 -5.0E+08 -4.6E+08 -4.3E+08 -3.9E+08 -3.5E+08 -2.7E+08 -2.3E+08</td>
</tr>
<tr>
<td>Transalpino alternative s option</td>
<td>-4.3E+08</td>
<td>-4.2E+08 -3.6E+08 -2.9E+08 -2.1E+08 -1.6E+08 -0.7E+07 4.1E+07 5.4E+06</td>
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</tbody>
</table>

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APPENDIX 6.9-2: EXPECTATIONS ON FUTURE GROWTH IN MONTE CARLO ANALYSIS

<table>
<thead>
<tr>
<th>Risk Variable No. 1</th>
<th>GROWTH RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability distribution:</td>
<td>NORMAL</td>
</tr>
<tr>
<td>Range:</td>
<td>MIN 0.03</td>
</tr>
<tr>
<td>Standard deviation:</td>
<td>0.045</td>
</tr>
<tr>
<td>Degree of skewness:</td>
<td>-50%</td>
</tr>
</tbody>
</table>

![Risk Variables Report](image-url)
### Appendix 6.3-3: Deriving Net Benefits Relative to Status Quo Option in 2000 as a Function of Growth Rates

#### Growth Rate for Next 11 Years

- **0.135**

#### Net Benefits of Transandino Alternative Shuttle Option Relative to Status Quo Option as a Function of Demand Equivalents

<table>
<thead>
<tr>
<th>Demand Equivalent</th>
<th>Net Benefits (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200000</td>
<td>-4.9E+08</td>
</tr>
<tr>
<td>400000</td>
<td>-4.2E+08</td>
</tr>
<tr>
<td>600000</td>
<td>-3.6E+08</td>
</tr>
<tr>
<td>800000</td>
<td>-3.1E+08</td>
</tr>
<tr>
<td>1000000</td>
<td>-2.6E+08</td>
</tr>
<tr>
<td>1200000</td>
<td>-2.1E+08</td>
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<tr>
<td>1400000</td>
<td>-1.6E+08</td>
</tr>
<tr>
<td>1600000</td>
<td>-1.1E+08</td>
</tr>
<tr>
<td>1800000</td>
<td>-6E+08</td>
</tr>
<tr>
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<td>7.97E+08</td>
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<tr>
<td>4000000</td>
<td>8.81E+08</td>
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</tbody>
</table>

#### Linear Approximation of Net Benefits as a Function of Demand Equivalents

- **Slope**: 384.1076
- **Y-Intercept**: -6E+08

#### Net Benefits as a Function of Growth Rates (Substituting Formulas)

Net benefits: 1.13E+08
### MONTE CARLO ANALYSIS RESULTS: PROBABILITY DISTRIBUTION OF RELATIVE NET BENEFITS AS A FUNCTION OF GROWTH RATE PROBABILITY DISTRIBUTION

<table>
<thead>
<tr>
<th></th>
<th>Relative Net Benefits</th>
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<tbody>
<tr>
<td>Expected Value</td>
<td>-20895742.88</td>
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<tr>
<td>Standard Deviation</td>
<td>311818327.3</td>
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<tr>
<td>Minimum</td>
<td>-637431133.3</td>
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<tr>
<td>Maximum</td>
<td>1152838400</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>-14.923</td>
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<tr>
<td>Probability of negative outcome</td>
<td>57.2%</td>
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<tr>
<td>Expected Loss</td>
<td>134892854.7</td>
</tr>
<tr>
<td>Expected Gain</td>
<td>113997111.8</td>
</tr>
<tr>
<td>Expected Loss Ratio</td>
<td>0.542</td>
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</tbody>
</table>
APPENDIX 6.9-5: MONTE CARLO ANALYSIS RESULTS: FREQUENCY DISTRIBUTION OF RELATIVE NET BENEFITS AS A FUNCTION OF GROWTH RATE PROBABILITY DISTRIBUTION
APPENDIX 6.9-6: MONTE CARLO ANALYSIS RESULTS: CUMULATIVE DISTRIBUTION OF RELATIVE NET BENEFITS AS A FUNCTION OF GROWTH RATE PROBABILITY DISTRIBUTION