Infrastructure Investment and Productivity: The Case of Nigerian Manufacturing

A Framework for Policy Study

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Discussion Paper

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Discussion Paper
# INFRASTRUCTURE INVESTMENT AND PRODUCTIVITY:
THE CASE OF NIGERIAN MANUFACTURING
A FRAMEWORK FOR POLICY STUDY

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PREFACE

This paper is the first in a series of papers to be produced within the research project, "A Study of the Impacts of Infrastructural Deficiencies on the Nigerian Industrial Sector and their Policy Implications". As part of the World Bank research program on urban infrastructure and productivity (see the Abstract of the Research Program), this research project is funded by UNDP, Lagos (NIR/86/008), and conducted jointly by the World Bank and the Nigerian Industrial Development Bank. In this paper, the authors present the guiding research framework developed for undertaking empirical studies and policy analysis.
ABSTRACT OF THE RESEARCH PROGRAM

URBAN INFRASTRUCTURE AND PRODUCTIVITY

As cities in developing countries continue to grow rapidly, the need to meet the increasing demand for urban infrastructure services has become an important policy problem, since failures to respond to such demand adequately affects productivity and the quality of life in those cities. In order to assist member countries through the World Bank's lending program in this area, there is a need to better understand: (1) the options for more efficiently providing and maintaining the delivery of various infrastructure services such as electricity, water supply, transport, telecommunications and waste disposal; (2) the ways by which inadequate services affect business operations and peoples' activities, hence the overall productivity of an urban area; and (3) potential cost savings from improved services. The World Bank has begun to implement a research program to address these issues. The work will be undertaken in one African country, Nigeria, one Asian country to be yet selected and possibly one Latin American country.

More specifically, the research will examine the following types of questions. On the demand side: how do firms respond to the constraints imposed by the deficiencies of various infrastructure services, considering both the quantity and quality of these services? What alternatives do firms have, and what are the costs of these alternatives to both the firms and to society? Is the private provision of infrastructure services a viable substitute for publicly provided services? On the supply side: what are the causes of failure to deliver services at the level required to meet demands? To what extent are such failures due to the lack of capacity expansion or due to poor operations and maintenance? In what ways do inappropriate pricing and user charge policies contribute to the problem by constraining revenue generation to support improvements? What options exist for the more efficient production and delivery of services in terms of investment, technology, institutions, regulations and financing?

The availability and quality of infrastructure services tend to vary across different locations and different users. Firms operate where they can easily meet their needs for various services. Public policies can influence the availability and quality of such services, and hence the productivity of individual firms and the urban area as a whole. The research results will develop: (1) the policy framework for making investment choices, and (2) the strategies for improving infrastructure services.
The paper reviews the Nigerian situation regarding the private provision of infrastructure services by manufacturers. Such private provision is observed all over Nigeria and in most manufacturing sectors. It occurs in electric power generation, water supply, intraurban freight and worker transport, telecommunications and waste disposal. Manufacturing firms have developed private provision responses which are identified and analyzed. Such private responses are grouped into seven regimes, of which four are currently observed to occur, and three are precluded from occurring due to existing regulations. A model of public infrastructure supply which is pertinent for developing countries is proposed and discussed. This model incorporates a modern treatment of the economics of monopolistic supply and pricing subject to quality constraints. A general cost-benefit analysis framework for evaluating the net social benefits of infrastructure improvements is also presented. Policy options which can be used to improve the efficiency of the current situation are examined and discussed. It is argued that the most promising options are likely to be those which encourage new modes of cooperative private provision among manufacturers, accompanied by deregulation, privatization, contestability, modern pricing and selective maintenance in the public agencies. The recommended options are especially timely within Nigeria's ongoing structural adjustment program.
Private (intrafirm) investments in infrastructure services are observed in the Nigerian manufacturing sector. This occurs because publicly supplied infrastructure services are either nonexistent, of poor quality or subject to chronic failures. The phenomenon is typical of many developing countries.

In Nigeria many firms in a variety of industries have undertaken infrastructure investments in (a) electricity generation, (b) water supply, (c) transportation, (d) telecommunications, and (e) waste disposal. In each of these areas, firms rely on the publicly available services supplemented by their own provisions or vice versa. While the extent of such private substitution varies greatly by industry, size of firm, type of infrastructure and location within the country, the phenomenon is widespread and appears to absorb significant resources that could be used more productively [28].

The provision of many types of infrastructure investments is subject to a high degree of scale economies: the average cost per unit quantity of produced infrastructure service falls with increases in the total quantity produced. Therefore, the private provision of infrastructure services increases the cost of infrastructure services, especially for firms which are small in size.

The economic inefficiency which results from the private provision of infrastructure services and from the duplication of the capacity that already exists in the public sector suggests numerous policies and private or public investment initiatives which are likely to yield considerable economic benefits. It is a contention of this paper that such options can be thoroughly evaluated from the perspective of microeconomic analysis. In particular, a research agenda which calls for the application of standard concepts from cost-benefit analysis is needed.

The objectives of this paper are as follows. First, we intend to provide a documentation of the infrastructural deficiencies that are currently observed in Nigeria for each major infrastructure type and to identify the key critical questions facing the country in the next five to ten years in each of these sectors. Second, we intend to draw on our observations of the current Nigerian situation in order to achieve advances in two substantive areas of development economics: (1) the microeconomic modeling of individual and joint firms' responses to infrastructural deficiencies by various means of private provision, (2) extensions to the literature on the optimal pricing and supply of public infrastructure services in developing countries by taking into account the competing presence of private provision by firms. Third, we intend to develop a comprehensive cost-benefit analysis framework for
evaluating various policies, strategies and scenarios of infrastructure improvements which allow private provision by firms as a viable and possibly efficient solution. Fourth, we aim to identify a number of specific public, private and joint policy options which appear most promising for Nigeria and are likely to be equally or more promising in other developing countries in an era where deregulation, decentralization and privatization are becoming increasingly popular themes within broad macroeconomic structural adjustment programs.

Part II discusses the current situation in Nigeria in terms of several situations which are representative of the private infrastructure provision problem. These observations are drawn from several field trips to the country during the last two years as well as from extensive prior documentation by the World Bank. The field trips included visits and detailed interviews of the managers of several firms and interviews of numerous government officials, as well as pretesting of a survey questionnaire which will be administered to a sample of Nigerian manufacturers [16].

Part III outlines the chief features of a microeconomic model of the firm which includes private infrastructure provision as an embedded technology within the firm's production function. This basic model is then subjected to refinements in order to adapt it to special situations which are representative of currently observed as well as currently unobserved but possible future responses by the firms. Seven different regimes of firm behavior are identified and analyzed. The mathematical details are relegated to Appendix I.

Part IV discusses the public supply of infrastructure provision and pricing behavior from a modern perspective and in a situation where the quality as well as the quantity of the infrastructure service is a decision variable, the demand is a function of quality, and quality itself is a declining function of the quantity demanded due to congestion effects. Such a model is applicable to Nigeria where power generation and other types of infrastructure like telecommunication suffer from frequent interruptions or fluctuations in service quality. These quality fluctuations are, in part, a result of congestion in the use of the system. The public agencies must consider the trade-offs between quality, quantity and price in determining the optimal supply policy. This poorly researched topic is considered and some new analytical aspects suggested by the Nigerian situation are identified and briefly explored from the perspective of modern industrial organization theory. Appendix II contains some background information and the mathematical formulation of the public supply model.

Part V of this paper discusses the treatment of the firm, industry and external impacts of infrastructure improvements. The theory of cost-benefit analysis which is applicable to infrastructure investments is summarized in Appendix III. A multiperiod cost-benefit framework which incorporates consumer and producer surplus changes is proposed.

Part VI identifies several categories of policy options which are likely to yield improvements in economic efficiency and enumerates the critical issues facing Nigeria in the next five to ten years with respect to each infrastructural type, with some preliminary recommendations. Various
policy options are suggested: there are institutional and regulatory options, options which center on financing and pricing, options of technology and investment choice and maintenance budgeting by the public sector. In addition, there are options of private initiatives at the level of a single firm and also at the interfirm level which are supported by the analysis of part III. The cost-benefit analytic framework developed in Appendix III is proposed as a framework for analyzing the economic efficiency rationale of these options. In this last part, a tentative perspective identifying the key issues facing each infrastructure subsector is put forward and some tentative recommendations are mentioned.

II. THE SITUATION IN NIGERIA

The current situation of infrastructural deficiencies in Nigeria must be considered within the broader context of the country's macroeconomic policy environment. In 1986 the country adopted a Structural Adjustment Program (SAP) which combines the stimulation of growth in non-oil exports through increases in domestic agriculture and manufacturing in parallel with the liberalization of restrictions on trade and exchange rates [27,29]. Nigeria's structural adjustment, in line with the recent experience of other countries, calls not only for price incentives and investment, but places an equal emphasis on demand management, deregulation, privatization, and institutional reform to enable effective administration in the collection of taxes and users' fees and in cost recovery for government programs. A stepping up of efforts to address the country's infrastructure constraints should be an integral part of the Structural Adjustment Program.

It is common knowledge that Nigerian manufacturers are plagued by frequent interruptions of publicly provided services such as water, electric power, transportation of freight and labor, telecommunications and waste disposal, and by the poor quality of these services when and where they are available [19,21,22,23,26].

The public agencies, with a large amount of capital investment already in place, fail to deliver these services at the levels required to meet demand. Such failures not only result in the waste of scarce resources but induce firms to engage in the private provision of the infrastructure services at the higher costs necessitated by the scale diseconomies of private provision.

The presence of private provision is well documented and readily observable. The Nigerian Industrial Development Bank (NIDB) which disburses the World Bank's industrial development loans, has documented that in response to uncertainties about publicly provided infrastructure provision, Nigerian manufacturers undertake a large sum of capital investment to provide their own services using their own resources [7,28].

The various activities with large capital expenditures undertaken by the Nigerian firms indicate that their ability to adjust to the relative costs of human, machine, material, or infrastructure service inputs is rather tightly constrained by the current technologies in use. Inevitably, one of the effects of the devaluation of the Naira within the recent Structural
Adjustment Program [27,29] is to raise some of the costs of private infrastructure provision, such as the price of electricity generators which are imported [19,30].

Because input substitution possibilities are limited, the firms operate inefficiently by providing their own infrastructure services which are important for their operations. Some degree of such private provision is true regardless of firm sizes, and the degree of inefficiency is usually much higher for small firms than large ones since the average cost of most types of infrastructure falls with the quantity of the infrastructural service produced.

Hence, those firms, mostly small ones that choose not to make capital expenditures for electricity generation or other infrastructure service provision, often incur comparable costs in other forms, such as foregone output and revenues, as a result of the failure of the public sector's service provision.

On the other hand, those firms that make capital expenditures for their own service provision have higher production costs and output prices and find it difficult to compete with their importing counterparts or in the export markets.

Firms could relocate to areas with better infrastructure services. This possibility, however, is limited in Nigeria because the capacity, regularity and quality of infrastructure vary from bad to worse within and across Nigerian cities. Based on a recent field trip by the authors, the situation of representative firms is easy to identify. It is useful to discuss the general situation by type of infrastructure service and to provide anecdotal examples from several firms that were interviewed.

(a) Electric power generation: This is the most important sector in which extensive private provision has occurred.

The Nigerian Electric Power Authority (NEPA) is responsible for supplying power to the entire country and is, in fact, the major supplier. The only place where a competing private electric company has been established is the provincial mining area centered around the town of Jos in Plateau State. This company produces electricity, supplying some of it to the local firms and mines and nearby cities and selling the bulk of it (about 80 percent) to NEPA at a profit.

Outside this arrangement which exists because of the establishment of the company at Jos during colonial times, before NEPA's network was extended to the Plateau State, there are regulations which prohibit the emergence of private electric companies. Also, firms which produce electricity for their own operations are not allowed to sell their surplus power to NEPA or to other firms.

Very recently, NEPA began subcontracting certain segments of its operations. A Japanese firm (Marubeni) is undertaking maintenance work for a power station and transmission facilities. This trend
may increase in the future since Nigeria's recently implemented Structural Adjustment Program calls for increased private sector participation and decentralization as a general strategy for fostering growth and improving efficiency.

Interviews of public officials, including the chief systems engineer of NEPA, confirmed the conclusion that the country's power supply problem is not one of insufficient generating capacity. In fact, NEPA operates at less than full capacity at all times. The main bottleneck is the transmission and distribution networks which suffer frequent grid collapses at the national and subnational levels. In addition, there are serious difficulties due to inefficiencies in planning, management and maintenance. There are also serious institutional failures in the pricing of electric power and in enforcing the collection of electricity charges especially from major users such as big government agencies.

According to NIDB, frequent power outages and voltage fluctuations affect almost every industrial establishment in the country and force them to undertake investments on electric generators in order to avoid production losses as well as damage to machinery and equipment. Typically, as much as 20 percent of the initial capital investment for a new plant of a firm monitored by NIDB is for electricity generators and boreholes alone.

In the case of a dry milk processing and canning plant in Lagos, even if the public power supply were available at proper voltage for as much as 90 percent of the time, the firm could not afford to eliminate its own generators because any voltage surges and drops at a critical time would threaten key equipment in the production process and result in much waste.

To illustrate the aggregate implication of such private provision costs, consider that a major textile manufacturer located in Lagos, estimates the depreciated capital value of its electricity supply investment as three million Naira. This firm, a heavy but not extreme user of electricity, employs about 2,000 workers at full capacity. At this 1,500 Naira per worker, the 6,000 Nigerian manufacturing firms (assuming an average of 100 workers each at full capacity) might hold 900 million Nairas worth of electricity generating capital equipment. To replace such a generating capacity at current prices would cost nearly triple that figure. According to an independent estimate, such a figure would suffice to improve the transmission and distribution facilities of NEPA to warrant the availability and quality of power supply for the entire country including the residential sector.

The above examples illustrate the magnitude of private investments in power generation. However, a big part of the problem has to do with the economic losses that occur when firms do not find it profitable to generate their own power. Examples of this situation can be found at both extremes of the size distribution of firms. On the one hand, there are very large operations, such as cement or
aluminum extrusion plants that are so energy intensive that
provision of their own power would be extremely costly requiring a
large scale in-house power plant in its own right. Therefore, it is
preferable for such firms to suffer shut downs 10 or 20 percent of
the time rather than to undertake such huge capital expenditures.
Plants in the sectors of petrochemicals, fertilizers, steel (blast
furnace) and some very large textile plants are in a similar
position of not finding it profitable to provide their own power
generation. On the other hand, small plants of perhaps less than 30
employees find it generally unprofitable to set up their own power
generators, because their operations do not have sufficient scale.

(b) **Water supply:** In this infrastructure sector the sinking of
boreholes by firms is nearly universal. Investments are also made
in installing water treatment plants.

In the case of the Greater Lagos region, the water supply situation
presents a picture much different from that of power generation,
because an abundant supply of water at low depths below the surface
is ubiquitously available in the area. It is therefore efficient to
sink boreholes and there is virtually no uncertainty that plentiful
water will be available from such boreholes. In fact, the economic
feasibility of this situation is apparent from the presence of
boreholes and treatment plants to supply water to certain affluent
residential enclaves in the Lagos area.

The presence of plentiful groundwater somewhat mitigates the large
scale economies which are usually present in water supply and
distribution in most areas which are not rich in groundwater.
However, it is important to stress that the solution is temporary.
As the water table below Greater Lagos recedes, the costs of private
provision will rise and the need to install an adequate public
supply system will increase.

Boreholes are far cheaper than electricity generators and the
switches and transformers needed with them. Nonetheless, private
investments in boreholes and treatment systems sum to a sizeable
capital investment since a single large borehole can cost over
200,000 Naira.

(c) **Transportation:** This is an important sector which has complex
effects on the operations of firms. First, one must distinguish
between the effects of personal and freight transportation, and in
the latter case one must separate intraurban freight transport from
interurban and interregional (including international) freight
transport.

In the area of personal transport, firms are affected by delays in
workers' arrival times to work. All of the firms we visited
reported such problems. The main concern is that although the
average distance between workers' residences and the plants is
relatively short, the time needed in commuting is inordinately long,
primarily because of the unreliability of public transport and the
long waiting times at bus stops in the Lagos area. About 60-80 percent of the staff of these firms is reported to spend 1-2 hours daily commuting.

Long and uncomfortable commutes in crowded buses have effects on the productivity of workers and the wages they are likely to demand. Unfortunately, transport systems are largely external to the firms, and managers are not able to adequately compensate for such problems. In some cases firms can set up vans to pick up workers and deliver them to work or they may subsidize the purchase of a private car by an important employee whose timely presence at the plant is indispensable.

In traffic, just as in the other areas, the bottleneck is not in the lack of adequate road capacity but in traffic management. The lack of adequate traffic lights and traffic policemen was cited by several firm managers. Modest investments in these areas would greatly reduce commuting problems.

In freight transport, the problem of the firm is more complex. The national railways are plagued by maintenance and rehabilitation problems. Trains move at an average speed of 5 km/hr. There have been no fare increases in the last seven years and pricing remains inefficient. Furthermore, because of the built-in inefficiencies the marginal cost structure for railroad operations is extremely difficult to determine. As a result of this situation, transport by truck has, over the years, captured a large part of the total freight market at the expense of rail. Possibilities for optimizing the intermodal mix are severely lacking as are institutional arrangements for integrated transport coordination at the interregional level.

Nigerian Airways, a State-run company, fails to provide adequate service for passengers as well as freight [18]. The main problem is delays and frequent cancellation of flights, including on major international routes. The company has been running losses. This affects firms in the area of cargo handling and freight forwarding to the country's sixteen provinces which have airports. Recently, small privately run air transporters have begun to seriously challenge Nigerian Airways [18]. The development of such competition is seen increasingly as desirable under the new trend toward privatization.

In intraurban transport, some firms make investments to improve the reliability of their freight collection and distribution operations by purchasing and operating their own fleet of vans. State statistics [4,5] indicate continuing growth of vehicle and car ownership in the Lagos region which contributes to congestion and traffic bottlenecks.

(d) Telecommunications: The poor state of inadequate telecommunication services is widely known. In many cases, and especially during periods of heavy use, the probability of making a connection by telephone is very low. If a connection is made, the quality of the connection may be too unreliable. The managers of
the firms that were interviewed attested to the improvement in
telephone service over the years, but rated current services as
inadequate. In some cases they complained about the poor quality of
international connections.

As in the other infrastructural sectors, public telecommunica-
tion facilities operated by the Nigerian Telephone Company (NITEL)
also suffer primarily from operational problems. Pricing is
inefficient and current rates are very low for both local and trunk
calls. The billing system is very poor and government agencies,
although among the most intensive users, do not pay their bills.

The costs of inadequate telecommunication services on the firms are
reflected in numerous small capital expenditures on motorcycles for
couriers and on radio systems, and most importantly in many
separate expenditures of time and loss of productive hours as sales
people and managers travel about to deliver messages and hold
conversations that could be held in moments over a working phone
line. It is also easy to observe that the typical firm invests in
too many separate phone lines in order to increase its success in
making a connection.

The above comments make it clear that the inadequate state of
telecommunications results in the substitution of transportation
activities for communication purposes. This situation, doubtlessly
increases the state of congestion in transport networks and inhibits
firms from relocating outside of major business agglomerations. As
in power generation, a new trend toward privatization and decentral-
ization is detectable in telecommunications. Foreign firms
including Siemens and ITT have recently signed maintenance contracts
with NITEL. Recently, the government allowed a private foreign
firm, DHL, to operate in Nigeria. DHL charges a much higher fee
than the Nigerian Postal Service, but is quicker and more reliable
and thriving with good business.

(d) Waste disposal: Much needs to be done in the area of disposing
solid and liquid industrial wastes. The current situation requires
most firms to either dispose such wastes freely in the vicinity of
their plant or to contract with private waste disposal companies.
For example, a textile firm we visited dumps its industrial waste
water just outside its factory to an abutting street. It has
private arrangements for disposing solid wastes.

It is clear that the loose regulations (or their absence) about
waste disposal contribute to the compounding of environmental
problems if not all over Nigeria, then in major agglomerations such
as Greater Lagos. Such environmental degradation may appear minor
compared to the other problems the Nigerian economy is currently
facing. What is occurring, therefore, is a postponement of the
problem at the expense of higher cleanup costs to be borne by future
generations.
III. Firms' Responses: The Seven Regimes of Private Provision

To understand better the behavior of firms in an environment of inadequate public infrastructure, it will be important to develop a microeconomic theory of the firm with privately produced infrastructure services appropriately allowed to occur in the firm's production function. This is a complex problem which has not been covered in the theoretical literature. Also, such firm behavior has not, up to now, been the subject of applied and empirical research interest.

It is important that such a theory of the firm goes beyond the currently observed phenomena in Nigeria and allows a number of economic responses which become possible under a different set of institutional, regulatory and economic conditions which may prevail in the future in Nigeria or in other countries.

For example, firms in Nigeria could produce electricity for use in their own production process as well as for sale to NEPA and smaller firms located adjacent to them. This is not observed because current regulations prohibit the sale of electricity among private firms. Such behavior can have considerable efficiency benefits. In fact, the behavior may be an optimal strategy under some conditions such as the agglomeration of small firms around bigger ones in a utility pool or an industrial cooperative.

Seven regimes of behavior can be identified and require separate treatment within such a "theory of the firm" context. To explain these regimes clearly, we will examine the case of power generation. The reader should recall that a similar treatment applies to the other types of infrastructure. Therefore, power generation is used as an example and the relevance of each regime in the case of other infrastructural types is discussed briefly.

In identifying and analyzing these regimes we have adopted the static theory of the firm as the relevant framework. However, it is useful to note here that the quality and quantity of infrastructure services can also play a role in the dynamic response of the firm. In particular, inventory and production scheduling and the delivery times for inputs and outputs are often seriously influenced by anticipated or real breakdowns in infrastructural services. Firms attempt to take advantage of any seasonal variations in the reliability of key infrastructural services by building up inventories during more reliable periods and depleting such inventories during less reliable periods. The ability of firms to undertake such adjustments has its costs. Also, such adjustments introduce a dimension of nonprice competition among firms within the same industry.

The Seven Regimes of Firms' Responses

We now turn to the seven regimes of firm behavior which are separately analyzed. In each of these regimes we will assume that the firm is competitive (a price taker) in both input and output markets. The mathematical formulation of the general model and individual regimes is relegated to Appendix I.
(a) The self-sufficient firm

In this regime, the firm produces all of its own power. Casual reasoning suggests that this regime should be rare, because the average cost of privately produced power might not be less than that of the public source. Nevertheless, this regime becomes profitable if interruptions in the public supply become too frequent. If this happens, then the costs of switching back and forth between the private and public supplies becomes too high and the firm has an incentive to completely detach itself from NEPA.

In Nigeria the regime of self-sufficiency is observed in the case of foreign multinational firms which provide their own power. The motivation of such firms may be in part a response to the anticipation of prolonged power shutdowns perhaps during periods of political instability. The same multinationals are also observed to insulate themselves in other ways. Such cases would suggest that self-sufficient private provision will occur even if the privately produced power costs a great deal more than the publicly available supply. To put it another way, the higher price of private power is worth incurring to insure against the possibility of prolonged power shutdowns as well as assuring a steady supply of quality power during normal times.

The regime of self-sufficiency is also suitable for certain firms with production processes which are highly sensitive to power supply switches. Such firms may also be modeled under regime c as we will see below.

The self-sufficient firm may be relatively rare in the case of power generation but is ubiquitous in water supply. It is widely observed that, at least in the Lagos area, firms of any considerable size sink their own boreholes and supply all of their own water needs. This is economical because near-surface groundwater is abundant in the area and therefore the usual economies of scale in water supply tend to be insignificant.

Self-sufficiency in transport, telecommunications and waste disposal may be more difficult because of technological constraints and diseconomies of scope.

(b) The captive firm

A captive firm chooses not to produce its own electric power. Instead, it relies completely on the public supply network. Therefore, when a power failure occurs, the firm's production process is interrupted and a loss in output occurs. Such a firm registers a double economic loss: loss of output during the power disruption and continued factor payments such as rents, wages etc. during this unproductive period.

A British run cement factory near Lagos is a good example of such a firm. The cement plant's operating capacity is large but not large
enough to warrant building its own power plant. The NEPA supplied
electricity is sufficiently cheaper than the cost of running such a
private power plant, that the cement factory chooses to utilize
public power even at the expense of the mentioned losses.

Clearly captive behavior is possible in the case of water supply but
not as frequently observed because of the lower cost of sinking
boreholes. Captive behavior is much more likely in telecommuni-
cations, transportation and waste disposal.

(c) The self-sufficient firm with public stand-by

In some production processes, the sensitivity of the plant
operations to a stable supply of power is very high. In such plants
frequent power outages can result in severe damage to machinery.

To prevent the possibility of such "burnout", some firms will prefer
to rely on their own power supply at all times during the day except
during off-peak hours when the probability of a public power outage
is very small. During these times the plant will switch to the
public supply of power provided that the public supply is
sufficiently cheap. This strategy works well only when there are
well defined periods of time when the probability of "burnout" can
be safely assumed to be zero.

The self-sufficient firm with public stand-by is a hybrid between
the self-sufficient firm and the captive firm: during the peak
period, the length of which is known with certainty, the firm
operates as a self-sufficient firm and during the off peak period,
also of a certain duration, the firm operates as a captive firm.

The concept of a peak period is not relevant in the case of water
use in Nigeria, therefore this regime is not applicable to water
supply.

In the case of transportation, a similar behavior occurs for firms
which transport their own workers during the rush hour and rely on
the public transport systems during the rest of the day. Similar
behavior is also feasible in telecommunications.

(d) The 'stand-by' firm

A 'stand-by' firm invests in its own generating capacity by
maintaining one or more generators, while relying primarily on the
public power supply. When a power failure occurs, the firm switches
to its own generators to keep its production process uninterrupted.

It is reasonable to assume that the stand-by generators are operated
with the optimal choice of labor, capital, fuel and other inputs.
Therefore, the output produced by the firm during the normal
operation is greater per unit of time than the output produced by it
during stand-by operation. This is reasonable to assume, since
privately generated electricity often costs more than publicly
generated electricity. Therefore, the stand-by firm, like its captive counterpart, also experiences an output loss. However, this loss comes from switching from the more efficient to the less efficient form of electricity and is not as severe.

The field trip to Nigeria produced numerous examples of stand-by firms in the Lagos region. Among them were a dry milk canning plant, and a major textile manufacturer. Each of these operations had two stand-by generators and used them regularly during power failures.

Stand-by behavior is not relevant in water supply but it is explanatory of firms using their own transport and communication devices when the public systems are stalled with excessive congestion.

(e) The satellite firm

In this regime, the firm chooses to purchase its electricity from another firm during breakdowns in the public supply of power. This behavior is similar to that of the stand-by firm but the stand-by power is purchased, not produced. Assuming that the price of the power purchased from the producing firm is not much higher than the price of the power purchased from the public supply and the quality of the power is better, satellite behavior will prevail unless one of the other regimes is more profitable. Another requirement for satellite behavior is spatial proximity between the producing firm and the satellite firm because this minimizes the cost of power transmission.

To our knowledge, satellite behavior is not currently observed in Nigeria. Undoubtedly this is so because current regulations do not allow firms to sell any excess power to other firms. We believe that this regime could be the basis of a number of innovative investment strategies which could be promoted by public-private cooperation as discussed in part VI.

Satellite behavior is also possible in the area of water supply, but is seldom observed in Nigeria. Most firms with the possible exception of the very small ones find it feasible to provide their own boreholes. However, it might be possible that services can be provided for smaller firms by adjoining larger ones.

The lending or selling of transportation and telecommunication services between firms is also possible but again not as likely to occur as the trading of power.

(f) Joint production

In this regime, a firm finds it profitable to produce a surplus of power relative to its needs and to sell the surplus either back to the public source or more profitably to satellite firms located near
it. Such a firm is the usual joint producer (of its product and electricity) recognized in microeconomic theory. Joint production was not observed in Nigeria but it could clearly be profitable when certain conditions exist. First, there must be satellite firms in close proximity, or NEPA must be willing to purchase excess power generated by the producer. Second, the size of the producer's plant must be such that it is efficient to produce more power than that needed by the plant's primary product during periods of failure in the public supply.

The joint production regime makes it possible for firms to build their own power plants and thus protect themselves against large output losses while at the same time recouping the cost of private provision by selling excess power at a profit. Joint production can also allow small firms to afford larger generating facilities by selling the excess power.

Possibilities of joint production are available in the other infrastructural sectors as discussed under the regime of satellite behavior. The two regimes of joint production and satellite behavior are complements: one is not feasible without the other.

(g) Shared production

Finally, a logical alternative is for a number of firms of approximately equal size to join together and build their own shared power plant to provide electricity. This regime reduces the average cost of power generation by creating the efficient scale and gives assurance of acceptable quality. A requirement for it to work is that a concentration of firms exist in close proximity, and that appropriate institutional incentives be available to reduce the transaction costs of the required cooperative behavior.

The "economic theory of clubs" [11] and the theory of public goods can be used to model the shared production of electricity within such a system. Economic considerations play a role in two respects.

First, the "club" of joint producers decides to exclude additional club members when the marginal benefits of another member are less than the marginal costs of serving such a member. Second, power generated by the club may be sold to other firms or to the public sector. If so, then the club can establish a price for the consumption of electricity within the club. If the club is entirely closed in the sense that it produces no more than the quantity of electricity it needs, then the pricing of electricity within the club is more complex and involves bargaining between the club members. For example, larger club members are likely to be more independent and their departure from the club can result in a large loss in scale economies thus raising the cost of power to the remaining members. Therefore, larger club members have a bigger bargaining power and can thus force smaller members to pay a premium for club membership. If the club can provide a supply of power which is more reliable than the public source, then club members
would be willing to pay such a premium, with the magnitude of the premium rising as the size of the member gets smaller.

A drawback of the shared production regime is the high transaction costs incurred in setting up the club. The negotiations between club members increase in complexity with the number of members. If such transaction costs are high, shared production regimes will not emerge. Therefore, an area of useful public regulation is the establishment of utility pools or industrial cooperatives, in which the composition of clubs and the rules of shared production are predetermined by the public sector. Such schemes would greatly reduce transactions costs and encourage shared production to take place.

The possibility of shared production exists in all types of infrastructure: water supply, transport, telecommunications and waste disposal. Furthermore, shared production can be used not only to take advantage of the scale economies inherent in each of these infrastructural sectors but also to provide all of these services simultaneously and thus take advantage of any economies of scope as well as scale. For example, returning to the context of the industrial cooperative discussed above, why should not the club members who enter such a cooperative subcontract an infrastructure provider, for example a private utility company, that will provide all of their infrastructural needs including water supply, transport of workers, communications, disposal of waste, etc.? Such an infrastructure provider can realize considerable economies in administrative costs and in the unnecessary duplication of such costs by many firms. Again, such possibilities require regulatory and institutional change and innovation.

IV. A MODERN PERSPECTIVE FOR PUBLIC SUPPLY POLICY

A second important aspect of the Nigerian situation is the behavior of public infrastructure suppliers such as NEPA or NITEL. In approaching this problem, it is possible to rely on a well developed literature on electric power and public utility pricing [3,13,14,15,31,32] which can provide the basis for modeling the other infrastructural sectors as well. However, while the literature is well developed and has been applied to the context of developing countries we believe that it is not directly applicable to situations such as Nigeria. We present the following arguments to serve as the basis for an alternative analytical framework that captures the reality observed in Nigeria and other countries.

(a) Marginal cost pricing: The literature contains a bias toward long run marginal cost pricing of public utilities and in particular in the power supply sector. The marginal cost calculations are presumed to be borrowable from developed countries. However, the management and maintenance cultures of developing countries contribute to a different and more complex cost structure which should include transactional and administrative (and other not easily quantifiable) costs as a big component. Therefore, the
presumed engineering relationships are not adequate and are not transferrable.

Even if the relevant marginal cost functions can be determined, there is still the traditional critique of marginal cost pricing which must be kept in mind. It is well known that an unregulated monopoly which is profitable can become unprofitable when marginal cost pricing is imposed on it, as if it were a competitive industry. This situation is shown in Figures 1a and 1b of Appendix II. This problem is a critical weakness of marginal cost pricing because if a monopoly which is regulated in this way becomes unprofitable, then it must be subsidized. Over time, regulated monopolies will slip into regimes of subsidization and regulating agencies must monitor them carefully to make sure that such slippages are not a result of the anticompetitive effects of the regulations themselves. It would appear therefore, that marginal cost pricing regulation would have a tendency to further aggravate the institutional weaknesses which are observed in Nigeria by requiring careful monitoring by the government bureaucracy which is the weak link in the chain.

(b) Monopolistic competition: The current structural adjustment programs which are being implemented in Nigeria and other developing countries require that private provision initiatives be explicitly considered by the public sector as having potential efficiency benefits. Thus, if the theory of monopoly were to be used to explain the behavior of a public power supplier such as NEPA, then this theory should be modified to take into account NEPA's competition with the consumers of power, i.e., firms engaging in private provision. The theory of monopolistic competition with outside goods [17], in this case stand-alone firms, offers a more satisfying alternative.

(c) Quality variations: The demand for publicly provided infrastructure should be recognized as depending explicitly not only on its price, but also on its quality and reliability. In the case of power supply, it has been recognized that two kinds of reliability, measured as voltage fluctuations and power outages, is important. However, the emphasis has been on stressing the dependence of costs on reliability and assuming that the elasticity of demand with respect to reliability is rather small or zero [15]. This assumption treats all firms as captive. The alternative regimes which have been examined in part III and which are observed in Nigeria suggest quite the opposite. With respect to other infrastructural types and transportation in particular, the state-of-the-art treats travel time and cost as explicit determinants of demand. The role of time in transportation may be likened in part to the role of reliability in power supply or in telecommunications because of its role as a shift variable in the demand function.

(d) Congestion effects: The analysis of public supply of infrastructural services should recognize that not only is demand determined by the quality of the infrastructural service, but also
that the quality of the service is influenced negatively by the demand. To put it more precisely, there are congestion effects which hinder the ability of public suppliers to compete with the regime of self-sufficiency. Furthermore, the usual remedies of peak load pricing which are intended to reduce such congestion effects to optimally priced levels are unsuccessful in many developing countries in the sense that there are power outages during peak hours. The treatment of congestion as endogenous is common in transportation and urban economics. It is well known that congested situations require the levying of an optimally set congestion toll the purpose of which is to reduce traffic and congestion to socially optimal levels.

(e) Efficient price discrimination — Ramsey prices: It was seen in part III that a variety of firms' responses are possible on the demand side. This means that the precise public service rate and quality of service needed to induce private firms to switch to the public supply is also complex and varied. Therefore, traditional regulatory prescriptions such as marginal cost pricing of public supplies are unlikely to yield good results. The modern theory of monopolies serving several different markets has established that it is usually efficient to charge a different price in each market. In particular, these prices are related to the elasticity of demand in each market and the marginal cost of serving each market when both of these quantities differ across markets. A formalization of such efficient prices has led to the well known Ramsey pricing formula under several restrictive assumptions about market demands. These are briefly reviewed in Appendix II.

It is also known within the modern theory of monopolistic pricing that unregulated monopolies often adopt price discrimination strategies which in fact resemble Ramsey or quasi-Ramsey prices. Therefore, it may be argued, that not much is gained from imposing regulations which seek to enforce efficient price discrimination.

Judging from this perspective, public utilities such as NEPA or NITEL and various parastatal organizations and freight carriers may contribute to economic efficiency by improving their pricing mechanisms by adopting explicit non-marginal cost strategies [1].

Any pricing approach which resembles Ramsey prices allows the monopoly to price each market above the marginal cost of serving it. The excess over the marginal cost is that market's contribution to the firm's overhead. If the monopoly cannot break even with this type of pricing because its overhead is too high, then it is possible to allow it to discriminate within each market by charging different unit prices to different users according to the quantity consumed by them. Such price discrimination is often more efficient than subsidizing the monopoly for the uncovered part of its overhead.

Another pricing regime is the two-part tariff. Under this regime an entry fee which differs by market is paid by those users who wish to
subscribe to purchase the service. While this entry fee contributes to overhead, a price which equals marginal cost is also charged and is paid by the user per unit of quantity purchased. A further variation is the self-selecting two part tariff. This regime combines the idea of the two part tariff with the concept of quantity discounts. The monopoly offers the user a combination of two part tariffs which differ in both entry fee and unit price according to the quantity which the user proposes to purchase.

Such modern pricing approaches are particularly valid for NEPA which faces transmission costs and reliability problems which are highly location and user (i.e., market) specific. There are undoubtedly groups of users who would suffer little from being disconnected from NEPA while contributing considerably to lower public supply costs as their disconnection reduces congestion and allows NEPA to improve service to other users. A flexible self-selecting two-part tariff structure with appropriately determined entry fees would allow such situations to be identified and exploited for higher economic efficiency.

Currently, NEPA operates as a subsidized public monopoly with a partially cost recovering tariff which, however, has not been adjusted since 1978. Therefore, it is highly doubtful that current pricing by NEPA is efficient.

(f) Contestable markets: The theory of contestable markets [2] may find a happy niche in the current situation of Nigeria and other developing countries with similar problems.

Within modern industrial organization theory, an industry in which fixed costs can be recovered by the resale of capital (namely there are no high sunk costs due to capital investments by incumbent firms) is considered contestable if entry costs are low. In such an industry incumbent firms, whether one or several, must deter entry by adopting competitive pricing. Otherwise, the presence of profits will attract potential entrants who can enter and exit at no cost.

The theory of contestable markets has implications for public sector behavior as well. The theory suggests that facilities with high sunk costs are better financed as public goods and provided to all potential entrants with equal ease of access. Highways, airports and large public utility plants are examples of such facilities. If these were to be provided privately the industries which use these facilities would not be contestable. Their public provision, coupled with liberal access and entry policies, insures the contestability of the markets.

Another implication of the theory is that contestability need not apply to the entirety of an incumbent firm's operations. It is not uncommon to have situations in which part of a firm's or public agency's operations can be successfully contested. In such cases, the public sector must insure those conditions which will allow or indeed insure the firms to privatize parts of their operations by opening them up to competitive bidding.
As part of the current structural adjustments, privatization of public suppliers by contracting with outside and in some cases with foreign management provides one way of improving efficiency. After all, this situation is not uncommon in the Nigerian private sector where many top firms are under foreign ownership, direction and management. In some cases such situations have successfully produced a new generation of elite Nigerian managers and technicians. It is worth noting, for example, that a firm we visited is a Swiss run company, another is an Indian run family business, and still another is under Dutch management, etc. Also common, is for parts of the Nigerian public sector to enter into selective strategic subcontracting with foreign firms to perform maintenance upgrading and other functions. It would seem unlikely that big improvements in the country's institutional structure can be achieved quickly without a broad program of the contestability of public sector operations.

Indications are that a broadly interpreted program of contestability and privatization would work well in Nigeria. The private power producer at Jos (a remnant of preindependence), the recent entry of DHL into the parcel shipment market and the subcontracting of some maintenance work on the NEPA network to Marubeni and the relatively recent opening of the air travel market to small private airlines are a few successful examples.

V. ECONOMIC IMPACTS OF INFRASTRUCTURE IMPROVEMENTS AND COST-BENEFIT ANALYSIS

This part briefly outlines the probable economic impacts of infrastructure improvements on the firms, the industry as a whole, and the consumers of final products. The relevance of consumer and producer surpluses in measuring the net social benefit of infrastructure investments and the framework for cost-benefit analysis are relegated to Appendix III.

(a) Firm impacts: Impacts on the firms occur because changes in the price or quality of infrastructure services directly affect the quantity of infrastructure service purchased and/or internally produced by the firm in question. The impact is either cost reducing or productivity improving. For example, if the price of the publicly supplied power is reduced, a cost improvement is experienced. If the quality of the public power supply improves because of a reduction in voltage fluctuations or in power outages, then the firm can increase its output without any change in input or output prices: the quality improvement translates into an improvement in the firm's production technology. It is a technological improvement (technical progress) or, more precisely, a fuller utilization of the existing technology which increases the productivity of firms and the industry.

(b) Industry impacts: These impacts may be further divided into two types: market impacts and external impacts or externalities.
(i) **market impacts:** These occur because the infrastructure improvements induce market competition among firms in the same or in different industries. For example, an improvement in the price of publicly supplied infrastructure can induce entry into the industry by new firms because the cost of production is reduced. This increases the supply of the industry's output and results in a reduction in the industry's output price.

The extent of such effects will depend on the competitive structure of the industry. The effect will be more rapid and pronounced in the industries with a highly competitive or contestable structure, than in oligopolies or monopolies protected by entry restrictions or effective deterrence of entry.

(ii) **external impacts:** these are those impacts which, are known as externalities and/or agglomeration effects, the latter being a special form of externality. They are distinguished from market impacts by the fact that neither the input nor the output prices are directly affected, but the productivity of the firm is affected.

Consider the case of general traffic improvements. Such a change can lead to general reductions in the time the labor force spends in commuting as well as in any uncertainty in the times of arrival at work. The result should be an improvement in the productivity of individual workers and a reduction in the inefficiency which results from uncertainty in plant operations. These general traffic improvements are a positive externality to the firm.

As a second example, consider a situation where the government sets up an industrial park with an adequate public water supply network. This can lead to the spatial concentration of many plants, with all the "intangible" benefits of an agglomeration. Such agglomeration effects are likely to be particularly strong in urban areas where communication, information sharing and other extra-market interactions among firms can enhance productivity.

Water supply, power generation and waste disposal do not normally generate external impacts unless their provision induces strong spatial concentrations of economic activity as in the above agglomeration example. On the other hand, certain types of infrastructure such as transportation and telecommunication networks can produce significant external impacts on the firms as well as direct impacts on input prices. This is one of the reasons why telecommunications and transport are more conveniently treated as public goods.

(c) **Consumer impacts:** Infrastructure improvements can impact firms by inducing changes in the demand for their output. From the point of view of the firm, such changes in consumer demand are external effects.
Road building and improved telecommunications can greatly reduce the search and travel costs of consumers, thus increasing the quantity they are willing to purchase at a given price. Such an increase in demand induces an increase in the industry's output price and an expansion in supply by the entry of new firms and increased production by existing firms.

The external impacts of infrastructure improvements on consumers may, in some cases, be more important to the firms than the direct impacts (internal and external) on the firms' production processes.

VI. ANALYSIS OF POLICY OPTIONS

This final part has two objectives. The first objective is to sketch an outline of the most promising policy options by broad categories and to offer a preliminary analysis of the likely costs and benefits of these options. The second objective is to summarize the critical issues which face the infrastructure subsectors in Nigeria in the relation of these sectors to industrial productivity and to offer preliminary recommendations which are to be substantiated during the research period.

A. Public Sector Options

The public sector faces difficult trade-offs among the following: (a) choice of technology, (b) choice of investment (capacity expansion vs. maintenance), (c) maintenance of existing systems, (d) transmission or delivery of service, (e) choice of financing mechanisms, (f) institutional reform (including revenue collection and administration), (g) regulatory reform (including pricing and market structure).

We believe that in most cases the recommended priority is the opposite of the above order. Complete deregulation is absolutely essential in unleashing the competitive forces inherent in the economy and in stimulating the emergence of both private firms providing services to others and also more private provision within existing firms. Establishment of efficient but non-marginal cost pricing is appropriate for public utilities such as NEPA and NITEL. Entry by firms and contestability should be encouraged in all fronts, even if such entry competes directly with public agencies. In finance, it would appear advisable that public subsidization of utilities be eliminated and government funds be conserved for investments in public goods types of infrastructure and the maintenance of such investments.

Institutional reform would address the administrative structure of public organizations and eliminate unneeded or ineffective operations with high X-inefficiency. Revenue collection, being in bad need of improvement, could be relegated to private firms with appropriate legal authority to collect. Privatization of inefficient agencies such as Nigerian airlines is also feasible and desirable.

Institutional and regulatory reforms would recover most of the deadweight losses inherent in the existing situation. Some additional
efficiency benefits may come about by selective maintenance and expansion as in the areas of electricity transmission and telecommunications.

B. Private Sector Options

Of the seven regimes discussed in part III, only four are currently observed in the area of power generation. These are: (a) captive firms, (b) self-sufficient firms, (c) stand-by firms; and (d) self-sufficient firms with public stand-by. The remaining three regimes of joint production, shared production and satellite behavior are not observed because of regulatory restrictions serving to protect the inefficient operations of NEPA from private competition.

The private sector options are to continue with the existing private provision modes. While this might raise the cost of electricity, it has benefits which occur because of the presence of steady supply with acceptable quality at all times. Furthermore, as deregulation and the withdrawal of subsidies forces NEPA to operate more efficiently, the cost of NEPA power is likely to rise. This will induce more firms to engage in private provision until such time as the reliability of NEPA power improves and the frequency of power shortages diminishes.

C. Joint Public-Private Options

As deregulation forces austerity on public providers, the demand for cooperative private schemes such as shared production or joint production/satellite behavior will increase. There will be possibly long periods of time when new private schemes must be tried until deregulation forces more reliable public supplies.

The efficiency benefits of shared production, for example, cannot be reaped unless public intervention or public policies and planning are used to reduce the private sector transactions costs involved in such options. For example, government planning agencies can encourage shared production regimes by providing incentives to form utility pools or industrial cooperatives where some infrastructural services such as roads and waste disposal systems are in place and where tax advantages or capital subsidies are offered to reduce power club set up costs. It will be difficult for such regimes to evolve in Nigeria without explicit public inducement. It will also be frequently advisable for the government to offer to buy the surplus power generated by joint producers or by shared production clubs.

D. Critical Issues and Preliminary Recommendations

At this stage we offer a tentative assessment of the most critical issues facing the infrastructure subsectors and the most efficient options available. These will provide a perspective to be substantiated and modified as we obtain our empirical results.

(a) Electric power

The key question here is the extent to which the costs of electric power generation can be reduced and the degree to which such
reduction contributes to overall economic efficiency. We have already indicated that the situation being complex as it is the most efficient strategy will probably require a broad deregulation which will bring to fore many public, private and joint public-private initiatives. Areas of improvement can be discussed in terms of pricing options and regulations on private provision.

In the area of pricing, the starting point is our observation that NEPA power is currently cheap. This compensates many business establishments, especially those captive firms which are too small to supply their own power, for the poor quality and low availability of power.

The chief reason for power interruptions is operational problems on the transmission network not the lack of generating capacity. In the long run it is desirable that a modern transmission network can be built and efficiently operated. In the short run, meanwhile, the pricing of public power needs to be fine tuned in order to improve efficiency and reduce interruptions. NEPA's current tariff system is inefficient because it does not take into account the private provision responses of firms. An efficient tariff would seek, in part, to reduce overloading of the transmission network by making power more expensive to large users who have stand-by capacity and thus improving the quality of power to small captive users. Ramsey-like discriminatory pricing among users differentiated by location would also improve efficiency.

The above pricing strategy can be pursued hand in hand with the relaxation of regulatory constraints on private provision such as the sale of surplus power among firms. This would increase the level of competition in the generation of electricity. Efficiency can also be improved by privatizing parts of the public power supply sector such as the maintenance of equipment, the transmission of power, and the training of personnel.

(b) Water supply

The supply of groundwater in the Lagos area being plentiful and relatively inexpensive, the key question is not whether, but rather when a modern public water supply system should be developed for Greater Lagos and whether, in the interim, priority should be given to other regions of the country.

It appears that the optimal strategy for this sector is to allow the current private provision practices to continue for some time into the future while exploring mechanisms to induce firms to share water supply technology in the short run within broader schemes such as utility pools. Eventually, it will be desirable to make the transition to a publicly operated water delivery system.

In terms of intersectoral resource allocation, water supply should take the back seat to power supply in the short run, until the marginal costs of boreholing become sufficiently large to induce a shift to technologies with higher scale economies.
(c) Telecommunications

The extensive agglomerative and hard-to-quantify benefits of an improved telephone system are potentially stunning even though the direct and indirect expenditures by firms may appear small. Therefore, a project to modernize telecommunications ought to be given the highest priority and should proceed at full speed.

This sector requires major expenditures to modernize switching operations and possibly the installment of new equipment.

(d) Transportation

As in telecommunications, but much more quantifiable, are the benefits of improved rail and air transport interregionally and internationally. Numerous opportunities for deregulation, privatization and contestability should be exploited. Pricing and revenue collection mechanisms should be modernized.

In urban transport, and in Greater Lagos in particular, traffic management and maintenance improvements should be given priority over capital intensive projects.

(e) Waste disposal

The country needs appropriate waste disposal and environmental protection regulation. While this needs the attention of the government, the role of the government should be confined to designating waste disposal rules and providing treatment facilities. The actual disposal activity should be left to the firms themselves or to the private waste disposal enterprises which would emerge in an unregulated environment.
APPENDIX I

Specification of the Firm Model

In this Appendix we present the mathematical formulations of the economic behavior of the firm under the most important regimes discussed in part III. The general specification is presented first.

A. General Specification of the Model

To begin, we will define the following notation:

- $Q$: the output of the firm.
- $X$: the vector of inputs (factors of production except electricity) used by the firm to produce the output. $X$ includes primary inputs such as land, labor, capital, intermediate inputs and raw materials.
- $E$: the quantity of electricity (power) used as an input to produce the output.
- $Y$: vector of inputs needed to produce electricity. $Y$ includes capital (power generators), fuel, land (generator housing) and specialized labor needed to operate and maintain the firm's generators.
- $I$: the vector of infrastructure services external to the firm. $I$ includes all infrastructure services which increase the firm's productivity without being controlled by the firm. These are public goods types of investments in roads, telecommunications etc.
- $\mu$: the quality of the publicly supplied power, measured in
terms of the extent of voltage fluctuations.

\( \sigma \): the failure rate of the publicly supplied power measured by the proportion of time during a production period when the power supply is completely interrupted \((0 < \sigma < 1)\).

\( \delta \): a zero-one decision variable which indicates if the firm uses the public supply \((\delta = 1)\) or does not use the public supply \((\delta = 0)\).

\( F(I, \delta \mu, \delta \sigma, X, E) \): the firm's production function. Note that the external infrastructure services, \(I\), the voltage fluctuations, \(\mu\), and the failure rate, \(\sigma\), act as shift variables in the firm's production function. If the firm chooses not to use the public supply \((\delta = 0)\) then it is immune to the adverse effects of voltage fluctuations and power failures.

\( G(Y) \): the production function for power generation available to the firm as an embedded technology.

\( P_q, P_x, P_e, P_y \): unit market prices of the firm's output, factors of production, electricity and power generation inputs. It is assumed that the external (public goods type) infrastructure service \(I\) is freely available to the firm, namely the firm is not taxed for these general services.

It is important to consider more precise specifications of the production function \( F(\cdot) \). For example, consider the following generic forms:

1. \( F(\cdot) = A(I, \delta \mu, \delta \sigma) f(X, E) \),
2. \( F(\cdot) = A(I) f(X, a(\delta \mu, \delta \sigma)E) \),
3. \( F(\cdot) = f(A(I)X, a(\delta \mu, \delta \sigma)E) \).
Production function (1) is the case of factor neutral infrastructure technology which corresponds to the case of factor neutral technological progress in production theory. The external infrastructure services, I, or the pattern of publicly supplied power, \((\mu, \sigma)\), enters only as the scale factor of the production inputs. This means that an improvement in these technologies raises the output the firm can produce with a given combination of inputs by making each input more productive at the margin, but leaves unchanged the rates of technological substitution between any two inputs (the shapes of the isoquants are unchanged).

Production function (2) is the case of factor neutral external infrastructure services, I, coupled with electricity augmenting public power technology. The function \(a(.)\) is a scale function which influences the power input only \([a(.)=1\text{ if } \delta=0]\).

Production function (3) is the case of factor augmenting external infrastructure technology coupled with electricity augmenting power supply technology (as in (2)).

In both (2) and (3), improvements in infrastructure technology have nonneutral (augmenting) effects on the rates of technological substitution between two inputs. Some examples are worth considering.

Suppose that the component of I which represents road improvements affects the productivity of labor by reducing inconvenience due to commuting but leaves unchanged the productivity of land, machines, raw materials and intermediate
inputs. Then, (3) is the appropriate specification and \( A(I) \) enters as a multiplicative factor for labor alone.

Consider the likely situation that improvements in the quality of public power supply affect only the productivity of the power input, \( E \). Then, (2) or (3) is the appropriate specification and the scale function \( a(.) \) enters as a multiplicative factor for \( E \) alone. We would say that road improvements are labor augmenting while power delivery improvements are electricity augmenting.

B. The Regimes of Private Provision

(i) The self-sufficient firm:

A compact mathematical formulation of self-sufficient behavior is as follows:

\[
\begin{align*}
\text{MAXIMIZE} & \quad \Pi = p_q F(I,0,0,X,E) - p_x X - p_y Y \\
\text{subject to} & \quad \text{MINIMIZE} \quad p_y Y \\
& \quad \text{subject to} \quad G(Y) \geq E.
\end{align*}
\]

The firm has set \( \delta = 0 \) because it has decided not to rely on the public power supply. Therefore it is immune to voltage fluctuations and power outages (\( \mu \) and \( \sigma \) do not enter the production function: their values are set to zero). The above is a nested profit maximization: the firm maximizes its profits subject to an inner (embedded) minimization problem. In this inner problem the firm produces its power needs at minimum cost.
The inequality constraint in the inner problem allows the firm to produce more power than it needs, but this constraint will always hold as an equality since sale of excess power is not possible.

The above formulation simplifies to the following, by solution of the inner problem and substitution into the outer objective function:

\[ \text{MAXIMIZE } \Pi = p_q F(I,0,0,X,G(Y)) - p_x X - p_y Y \]

(ii) The captive firm:

The mathematical formulation of captive behavior is as follows:

\[ \text{MAXIMIZE } \Pi = p_q (1-\sigma) F(I,\mu,X,E) - p_x X - p_e E \]

In this formulation, the firm's output loss is at the rate of \( \sigma \). This assumes that the periods of power failure are randomly distributed throughout the production period and that the output flows out of the plant at a uniform rate during the production period. Such a production process may be called a continuous process. The firm ends up paying for the unused part of the factors of production (except electricity), because even though it knows \( \sigma \), the total proportion of time when power will fail, it cannot anticipate the duration and frequency of random power outages.

One specification of the production function could be:

\[ F(I,\mu,X,E) = A(I,\mu) f(X,E) \]

In this specification, the effect of voltage fluctuations, \( \mu \), is factor neutral.
A second formulation may be more appropriate if the firm's production process more closely resembles a batch process. In such a case:

\[
\text{MAXIMIZE } \Pi = p q F(I, \mu, (1-\sigma)X, E) - p x X - p e E.
\]

where the production function may be specified as,

\[
F(I, \mu, (1-\sigma)X, E) = A(I, \mu) f((1-\sigma)X, E).
\]

(iii) The stand-by firm:

The mathematical model of the stand-by firm using a continuous production process is as follows:

\[
\text{MAXIMIZE } \Pi = p q (1-\sigma) F(I, \mu, X, E_1) + p q F(I, 0, X, E_2)
\]

\[
\begin{aligned}
&- p x X - p e E_1 - p y Y \\
\text{subject to:} &
\end{aligned}
\]

\[
\text{MINIMIZE } p y Y
\]

\[
\text{subject to: } G(Y) \geq E_2
\]

(iv) The satellite firm:

The mathematical formulation of satellite behavior is as follows:

\[
\text{MAXIMIZE } \Pi = p q (1-\sigma) F(I, \mu, X, E) + p q F(I, 0, X, E)
\]

\[
\begin{aligned}
&- p x X - p e E_1 - p e E_2 \\
&x e_1 1 e_2 2
\end{aligned}
\]

Here, the subscript 1 denotes the publicly supplied power and the subscript 2 denotes the power purchased from another firm which produces excess electricity.
(v) Joint production:

The case of joint production can be modeled as follows:

\[
\begin{align*}
\text{MAXIMIZE} & \quad \Pi = p_q F(I, 0, 0, X, E_1) + p_e E_2 - p_x X - p_y Y \\
& \quad (X, E_1, E_2) \\
\text{subject to} & \quad : \\
\text{MINIMIZE} & \quad p_y Y \\
& \quad (Y) \\
\text{subject to} & \quad : \\
& \quad G(Y) \geq E_1 + E_2
\end{align*}
\]

In this formulation, the firm's revenues consist of sale receipts from the output as well as sales receipts from surplus power.

This problem can be condensed further as follows:

\[
\begin{align*}
\text{MAXIMIZE} & \quad \Pi = p F(I, 0, 0, X, G(Y) - E_2) + p_e E_2 - p_x X - p_y Y \\
& \quad (X, E_2, Y)
\end{align*}
\]
APPENDIX II

Specification of the Public Supply Model

A. Marginal Cost Regulation of Monopoly

The two-part Figure below shows the conditions under which marginal cost pricing regulation can cause a profitable monopoly to become a subsidized operation. In the absence of regulation, the monopoly produces at the point where marginal cost and marginal revenue are equal. Regulation requires the monopoly to produce where marginal cost and demand (or average revenue) intersect. As shown in Figure 1b, when the intersection of marginal cost and demand is below the average cost curve, the regulated monopoly incurs a loss (efgh), whereas if left unregulated it would still be profitable as shown by the area abcd in Figure 1b.

Figure 1a

Figure 1b
B. Ramsey Prices and Two-Part Tariffs

For a monopoly serving a number of separate markets with independent demands (and an economy satisfying some additional assumptions), Ramsey prices are zero-profit prices for which there is no Pareto superior adjustment. For any two markets \( i \) and \( j \), the prices are related as follows:

\[
\frac{\epsilon_i}{p_i - mc_i} = \frac{\epsilon_j}{p_j - mc_j}
\]

Here, the \( \epsilon \)'s are the elasticities of demand, the \( p \)'s are the prices and the \( mc \)'s denote the constant marginal cost of serving a market.

The following diagramatic representation shown in Figure 2 applies. The property of Ramsey prices is such that \( AB/BC \) is equal in all markets and the sum of overhead coverages across all markets equals the overhead. The two-part tariff is shown in Figure 3.
C. The Modern Public Supply Model

In developing a model of the unregulated public utility we are directly addressing the behavior of power and indirectly that of telecommunication authorities. The model also applies to water supply and waste disposal providers as well as to common intraurban or interurban freight carriers with some modifications in the last two cases since these activities are more competitive in market structure. Urban transportation is an exception in that the service provided has a very high degree of publicness and is thus better treated as a public good.

We define the following notation where \( j = 1 \ldots J \) are the distinct markets served by the public supplier. These markets can
be defined as classes of firms by size of firm, by location of firm or by type of firm.

\( N_j(e_j, p_j, \mu_j, \sigma_j) \): the number of firms in market \( j \) which choose to subscribe to the public power utility when the entry fee is \( e_j \), the price is \( p_j \), the voltage fluctuations are \( \mu_j \) and the rate of power failure is \( \sigma_j \). Note that these firms do not necessarily use the public supply exclusively (unless they are in the captive regime).

\( D_j(p_j, \mu_j, \sigma_j) \): the quantity of power demanded by the representative firm in market \( j \) which has entered the public service.

\( Q_j \): quantity of full capacity power transmitted to market \( j \).

\( C_j(Q_j, \mu_j, \sigma_j) \): transmission cost to market \( j \) when the qualities are \( \mu_j, \sigma_j \).

\( C(\Sigma Q_j) \): full capacity power production cost function.

\( \mu_j = f_j(Q_j) \): congestion function which gives the level of voltage fluctuations as a function of the delivered quantity.

\( \sigma_j = g_j(Q_j) \): congestion function which gives the power outage rate as a function of the demand for power.

The power authority's unregulated (profit maximizing) problem can be stated as follows:

\[
\text{MAXIMIZE } II = \sum_j e_j N(e_j, p_j, \mu_j, \sigma_j) + \sum_j p_j N_j(e_j, p_j, \mu_j, \sigma_j) D_j(p_j, \mu_j, \sigma_j) \\
- \sum_j C_j((1-\sigma_j)Q_j, \mu_j, \sigma_j) - C_j(\Sigma Q_j)
\]
subject to the following for each market $j$:

$$N_j(e_j, p_j, \mu_j, \sigma_j) D_j(p_j, \mu_j, \sigma_j) - (1 - \sigma_j)Q_j \leq 0$$

$$\mu_j = f_j(Q_j)$$

$$\sigma_j = g_j(Q_j).$$

The revenues of the monopoly are made up of entry fee revenues and unit price revenues summed over all markets. Both the demand for subscribing (entry) to the service and the quantity demanded are elastic in each market. The capital variable costs are a function of total production capacity and the variable cost of supplying each market is a function of the quantity supplied to that market (net of outage losses) and the level of voltage fluctuations and power failure rates. In turn, these quality variables are functions of the quantity supplied to each market. The demands of each market are independent of each other but functions of the quality variables. Note that this assumption of independent demands may be valid for electricity but is not valid for telephones: if firms’ demands for phones in one market is increased, the demands of firms in other markets will also increase, since businesses communicate with each other.
APPENDIX III

The Framework for Cost-Benefit Analysis

The benefits of infrastructure improvements can be measured if the effects of these improvements on the industry demand and industry supply functions can be modeled. Knowing these shifts allows us to measure the consumers' surplus and the producers' surplus. Figure 1 shows the consumer and producer surpluses in a particular industry.

A shift in the industry demand function can occur as a result of an improvement in consumer demand or the demand for the industry's output by other firms. Such a shift induces a movement up the industry supply function, resulting in higher output and higher output price (see Figure 2). A shift in the industry supply function, which can occur because of the internal or external effects of infrastructure improvements, is shown in Figure 3. This induces a movement down the industry demand function resulting in expanded industry output and lower output price. In both Figures 2 and 3 the sum of the consumer's and producer's surplus increases. This increase is the total increase in social welfare due to the demand shift in the former case and the supply shift in the latter case.

Figure 4 shows the effect of an infrastructure quality reduction on the industry supply function. Recall that the frequency of voltage fluctuations is a shift variable in the firm's supply function: the lower the voltage fluctuations, the higher the output produced by the firm given a package of inputs.
An increase in voltage fluctuations rotates the supply function to the left acting very much in the fashion of a Pigouvian tax: the firm producing a high level of output is affected more severely than the firm producing a small level of output. The figure shows the deadweight loss due to such a deterioration in service.

Infrastructure improvement programs may require major capital outlays. Therefore, their impacts and benefits must be considered in a multiperiod context. This allows us to consider alternative schemes for timing specific infrastructure improvement programs. Timing alternatives can be compared by calculating the present value of the net social benefits (NSB).

\[
NSB = \sum_t d(t) \delta CS(t) + \sum_t \sum_i d(t) \delta PS(i,t) - \sum_t d(t) COST(t).
\]

This equation gives the present value of net benefits as the sum of consumer surplus (CS) and producer surplus (PS) minus the costs (COST) of implementing the improvement program. \(d(t)\) is the social discount factor for time period \(t\), \(\delta CS(t)\) is the consumer surplus change in period \(t\) induced by the program, \(\delta PS(i,t)\) is the producer surplus change in industry \(i\) and period \(t\) induced by the program and \(COST(t)\) is the cost of the program in time period \(t\).

If the NSB as calculated above is positive, then the infrastructure improvement program might yield a potential Pareto improvement. There might be an aggregate social surplus that could be redistributed among the consumers and the industries in
such a way that none of these groups is worse off after the redistribution. For example, suppose that the consumers gained in period $t$ ($\delta CS(t) > 0$), but the industries lost ($\delta PS(i,t) < 0$). A Pareto improvement would occur if taxing the gainers across all time periods and using these tax revenues to compensate the losers across all time periods, still left a positive surplus. Such a calculation of the NSB is known as the ordinary method.

The ordinary method does not take into consideration the fact that consumers and producers can change their behavior after taxes and compensations are levied. Such changes in behavior are taken into account by using the income compensated method. In this method, we let $y$ stand for the compensating income increment (negative if a compensation, positive if a tax) and we compute the values of $y$ for each time period $t$ from:

$$\delta CS(y_{ot},t) = 0$$
$$\delta PS(y_{it},i,t) = 0$$

where $y_{ot}$ is the tax or compensation levied on households and $y_{it}$ is the tax or compensation levied on the $i$th industry at time period $t$. Then, a potential Pareto improvement exists if the NSB, given below, is positive.

$$NSB = \sum_{t} d(t) y_{ot} + \sum_{i} \sum_{t} d(t) y_{it} - \sum_{t} d(t) COST(t).$$

If the redistributions are actually implemented by levying the taxes and compensations, then an actual Pareto improvement occurs.

The above cost-benefit framework allows us to compare and
choose between two or more improvement programs. Given several programs with different NSB's, the one with the highest NSB value is preferred.

While the above framework is quite general and can be quantified, its success depends primarily on the assumptions which are made to calculate the surplus quantities. An issue is whether the surpluses should be calculated under partial equilibrium or general equilibrium conditions. A further problem is that infrastructure investment can shift the demand function of the consumer as well as the supply function of the firm as we have already discussed.

In addition to the correct specification of the market and external effects, it is important to include the effects of any externalities or agglomerative economies that result from the investment. For example, if NEPA improves transmission throughout the country, firms currently located in the Lagos region may relocate to more peripheral regions in order to take advantage of local markets there. While such firms reap overall benefits these are lessened by the loss of the agglomerative advantages that existed in the Lagos region.

An accurate calculation of the producer's surplus, therefore, requires identification of all these effects on the firms' production functions. To do this properly, it would be ideal to utilize a general equilibrium model with agglomeration and externality effects included. However, this is too ambitious and difficult to achieve because of data limitations. Therefore,
a more piecemeal approach which includes the internal effects and leaves out the external effects is more workable in practice.

Figure 1
The consumer surplus and producers surplus using industry demand and supply schedules.

Figure 2
Increase in social welfare due to an outward shift in the industry demand function.
(The producer's surplus is increased by the area abcd, of which abce is a transfer from the consumer to the producer and the triangle ecd is the producer's gain. The consumer's surplus increases if the area efgd is larger than abce (which was lost to the producers).
Figure 3

Increase in social welfare due to an outward shift in the industry supply function.
(This increases consumer surplus by the area abcd of which abce is a transfer from the producers and the triangle dec is a gain for the consumer. Producers gain if the area efgd is larger than the area abce which was lost to the consumer.)

Figure 4

Deadweight loss due to infrastructure quality deterioration and the induced shift of the industry supply function.
(The area abc which measured the sum of the producer’s and consumer’s surplus prior to the deterioration, now shrinks to the area adc, and the triangular area cbd is the deadweight loss induced by the increase in voltage fluctuations.)
REFERENCES


