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Efficiency and Productivity of Public and Private Networks of NTT

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I. Introduction

An enduring contribution of the twentieth century is the emergence and growth of the network infrastructure industries. Networks of transportation, energy,and communications opened up economic and social vistas by bringing communities,regions, and nations closer and closer together. Network growth has improved the economic productivity of the whole society substantially.

As with the other infrastructure networks, telecommunications network growth has been substantial. The early growth of telecommunications network was almost entirely centered in the development and extension of the public switched network. In more recent times there has been an expansion of private networks along with the continued growth of the public switched network. While the growth in telecommunications networks in general is very beneficial for economic productivity, a question of concern is whether the growth of private networks as opposed to the public switched network is productively advantageous. The purpose of this paper is to sketch out briefly some framing concerns with regards to investigating the efficiency and productivity implications of private network vs. public switched network expansion and then to discuss various aspects of the growth of public and private telecommunications networks of NTT, the dominant provider in Japan.

II. Efficiency and Productivity of Telecommunications Networks

In order to address the efficiency and productivity consequences of private vs. public network growth, it is helpful to set forth a few framing issues. These issues include the meaning and scope of efficiency and productivity, the frame of reference of efficiency examination and productivity measurement, the alternative configuration of public and private networks, and the pathways through which changes in the growth of public vs. private networks could effect efficiency and productivity levels of a given unit of concern.

Efficiency:

Traditional economic concepts of efficiency focus on the allocation of resources. If the market of services of public and private networks is in the state of what economists call "perfect competition," in which all buyers and sellers of the services are of small size and price–takers, then economic theory asserts that the allocation of resources will be efficient in the sense that there is no way to save the cost of resources while satisfying the given demand for public and private services. In reality, the market of public and private networks is not competitive; in many countries, the price of the services is set monopolistically by provider(s) if under the regulation of the government. In addition, the pricing of telecommunications services has an usual characteristic; the price of public services is composed of subscription charge and message–unit charge, whereas the price of private services is composed of subscription charge only. For these reasons, the market of public and private networks does not satisfy the condition of "perfect competition"; it may not function efficiently. This means that there may be possibility of saving the cost of producing public and private services by, say, proper regulation of the behavior of the provider. It is therefore worth while to examine the functioning of the market of public and private services from the standpoint of efficiency.

Productivity:

The concept of productivity considers the relationship of outputs to inputs. Productivity advancement is said to occur when the output/input ratio increases such that the input requirements for producing a given level of output decline. Productivity advancement represents a variety of production–side factors including improvements in efficiency, technological progress, and (when the term productivity is loosely construed) realization of scale economies and production complementarities.

In a broader sense, productivity can relate to overall economic welfare in terms of the relationship between general welfare levels and input/resource requirements. If the growth of economic welfare or societal satisfaction is obtained with a less than proportional growth of inputs, one can say that there has been productivity growth. In addition to the factors that contribute to output/input productivity growth, the improvement of efficiency or the introduction of new products and services can be an important cause of productivity advancement with respect to economic welfare.

Frame of Reference:

Several alternative frames of reference can be used in assessing the productivity consequences of private vs. public networks. At one level one can focus on a particular telecommunication service provider such as NTT, BT, etc. Or one can focus on the telecommunication service industry including all service providers. Alternatively one can focus on the productivity consequences with respect to a particular user or user class — or all users in general. And finally one can consider the combined productive consequences with respect to the combined impacts on providers and users.

When the frame of reference is focused on telecommunication service provision, the question of productivity advancement is addressed on the service provider side. The sources of productive advancement will be the elements of productive efficiency, technological progress, scale and production complementarity considerations. Advances in service provider productivity will be passed on to users though lower prices, to shareholders through higher profits, and to the economy in general through reduced claim on productive inputs. When the frame of reference is the user, the concern is the productivity of (say) the firm which uses telecommunication services as an intermediate input. On the side of the user the productive consequences of new communication services is especially important. Expanding the frame of reference from a single provider or user to all providers or all users — or to the combination of providers and users — is desirable in that the net effect of offsetting productivity effects can be assessed. For example, even though the productivity consequences of private vs. public network growth may be disadvantageous for the telecommunication service provider, if such growth stimulates new uses on the user side that have substantial productive consequences for the users the net effect for society could be desirable.

Network Configuration:

In assessing the question of whether the growth of private networks will have beneficial productivity consequences, one needs to consider the manner in which the private networks are provided. Three alternatives can be considered.

The first is where private networks and public switched network services are provided separately in both a physical and institutional sense. Under such a situation, multi–plant and multi–office firms (say) would construct their own communication network linking their plants and offices together while public switched network services would be provided through a traditional telecommunication service provider.

A second configuration is where public switched and private network services are provided by the same telecommunication service provider – as has been the situation with all major telecommunication service providers for quite sometime.In this situation the manner in which the private network service is provided is important for evaluating the productivity consequences. Early private network were basically isolated, dedicated physical facilities. later generations of private networks provided for co–location at a switching center with the connection on the other side of the switch. Rather than providing a 'dedicated wire', a dedicated slot in the multi-plexer would be provided. Thus private network users were connected into common/shared transmission facilities.More recently, software driven virtual networks connect private network users through the switch where switching pathways have been 'nailed up' for prescribed periods of time.

Pure private networks have drawbacks for many users. They require substantial up-front investments and the maintenance of a highly trained engineering staff. Also, pure private networks are more difficult to reconfigure as company needs change and as new technologies are introduced. Thus many companies have shown a preference for leased equipment and transmission facilities provided through the telecommunication provider. The emergence of the virtual networks provide the feel of private networks but operate through the switched network system. While the virtual networks reduce the costs of maintaining separate private networks, they are currently best suited for bulk voice service and not as well suited for data because of switching, amplification and delay problems of the public switched network.

A third configuration for the growth of private vs. public switched networks would be where various competing telecommunication service companies provided both private and public switched network services. For example, in the United States the larger telecommunication companies provide both switched service (for example AT&T's Megacom WATS, MCI's Prism, Sprint's Ultra WATS) and private line/virtual network services.

Pathways of Productivity Improvement:

As mentioned above, productivity advancement occurs when growth in outputs or welfare are achieved with less than proportional increased requirements for inputs. While the growth in productivity is dependant on improving efficiency, technology, production scale and complementarities, and (in the case of user welfare) new product/service development, a major question is the motivational pathway by which these improvements would be brought into existence. The alternative private network mechanisms sketched out above are relevant to the productivity question in terms of their impacts both on the physical nature of the networks and on the motivations for productivity improvement.

As a general proposition, if a public switched network system is fragmented with the spinning off of private networks, whether provided by the existing telecommunication company or others, the results will be a diminution in productivity. The fragmentation of the network results in productivity losses because of the loss of beneficial production externalities/complementarities. More inputs will be required to provide the same amount of service that had previously been provided.

However, fragmentation or apparent fragmentation may have positive net productivity improvements benefits under various situations, including:

1. Private networks enable the provision of new services or substantial quality improvements of existing services thereby resulting in productivity improvements by network service users.
2. Private network development (within an existing telecommunication service company) which is structured to be highly complementary to the public switched network (as with virtual networks) enable greater market stimulation thereby resulting in increased usage of the telecommunication system and the realization of production externalities.
3. Private networks provided by competing companies provides increased competitive pressure which encouraged increased operating efficiencies, more rapid technological development and deployment, and more rapid development and deployment of new services.

As a general rule, economists do not consider factor price change induced input substitution as contributing to productivity advancement. Such changes are, if the firm is operating on the isoquant indifference curve, merely movements along a production frontier and not an advancement of the frontier itself. However for firms which are not operating on the frontier and are dynamically choosing alternative technological pathways for production, price induced increases in telecommunication usage may contribute to the overall productivity advancement of the firm. If the price differential of private networks vs. public switched networks is large enough to encourage a firm to substantially alter its communications activities over what it would have done otherwise, the firm may realize productivity advances if the increased reliance on communication results in more efficient management and more efficient intertemporal production pathways.

III. Efficiency of Public vs. Private Networks

In this section, we will attempt to present a model which can give us an insight of the issue of efficiency in public and private networks. To derive a conclusion without complicated discussions, we will concentrate on the behavior of the user of telecommunications services concerning the choice of public vs. private networks, and the behavior of the telecommunications provider in relation to setting the *relative* price of public and private services. Further, we will assume that the total demand for, and the average price of, all telecommunications services, including public and private services, are given; it means that we do not consider issues arising from the growth of telecommunications networks.

In the following discussion, we will consider a monopolist provider of both public and private services, assuming away the possibility of competition in either market. We will be concerned only with the question how the provider allocates its resources to public vs. private networks. A simplifying assumption to be employed is that we abstract from the multiplicity of prices and the multiplicity of services. In particular, we will not be concerned with the timing of calls (i.e., the distinction between office hours, evenings, and weekend) or the distance of calls (i.e., the distinction of local and long–distance services).

Thus, we will consider only one price for public services and one price for private services.

At the end of this section, we will claim that a profit–maximizing provider tends to supply public services at a level higher than the socially desirable level, and tends to supply private services at a level lower than the socially desirable level. In other words, our theory asserts that there is an intrinsic reason for public services to be underpriced, and for private services to be overpriced, by the provider.

To explain our model, let us start with considering a monopolist provider supplying public services only. Let the variable I be the total number of subscribers; it will be fixed throughout this section. Let i be the index variable of I so that $i = 1, 2, \ldots, I$. Let n_{ij} be the average number of calls per day made by subscriber i to subscriber j ($i, j = 1, 2, \ldots, I$; $i \neq j$). Since the introduction of a private line to replace public services always takes place for a pair of subscribers, say, i and j, it is convenient to consider the sum of n_{ij} and n_{ji}: $n = n(i, j) = n_{ij} + n_{ji}$.

Let p be the unit charge for a call through the public network. As stated previously, we assume that all calls through the public network are homogeneous so that we consider a single price, p. Let $N = N(p)$ be the total demand for public services, i.e., the total number of calls made by the I subscribers through the public network. We assume that both p and N(p) are given and fixed. Let $M = I(I-1)/2$ be the number of all subscriber pairs. Since M is very large, we may consider the variable n, the number of calls per day by a pair, to change continuously. Let f(n) be the density of the subscriber pair with n calls per day. This means that f(n)Mdn is equal to the number of dn subscriber pairs with n calls per day. Let $\bar{n}$ be the maximum of n so that $0 \leqq n \leqq \bar{n}$. Then (See Figure 3.1),

$$\int_0^{\bar{n}} f(n)dn = 1, \quad \int_0^{\bar{n}} f(n)Mdn = M, \quad \int_0^{\bar{n}} f(n)ndn = N(p). \tag{3.1}$$

As stated previously, we assume that the demand for public services, which is characterized by $f(n)M = f(n, p)M$ and $\bar{n} = \bar{n}(p)$, is given for each n, p, and M.

Suppose now that the provider opens a private network by allowing each subscriber pair to choose either public services by paying at the rate p per call or private services by paying at the rate Q a day. The subscriber pair with n calls a day pays an amount equal to pn a day if it chooses public services, and pays the fixed rate Q a day if it chooses private services. This means that the subscriber pair with n calls a day chooses public services (private services, respectively), if

$$n \geqq q \quad (n \leqq q), \tag{3.2}$$

where $q = Q/p$ is the ratio of the private rate Q to the rate p of a public call. Observe that the variable q, the *relative price*, has the same measuring unit as the variable n, the number of calls per day.

We next consider the revenue to the provider. Let R_u and R_v respectively be the revenue from the public services and the revenue from the private services, when the provider chooses the break-even price ratio q. Then,

$$R_u = \int_0^q pnf(n)dn = \Big[F(n)pn \Big]_0^q - \int_0^q pF(n)dn = p \left\{ F(q)q - \mathscr{F}(q) \right\}, \text{ and} \tag{3.4}$$

$$R_v = \int_q^{\bar{n}} Qf(n)dn = p \left\{ 1 - F(q) \right\} q, \tag{3.5}$$

where (3.4) is obtained by means of integration by parts, $F(n)$ is the (cumulative) distribution function of $f(n)$, i.e., the integral of $f(n)$, and $\mathscr{F}(n)$ is the integral of $F(n)$ (See Figures 3.2A, 3.2B, and 3.2C):

$$F(n) = \int_0^n f(m)dm, \tag{3.6}$$

$$\mathscr{F}(n) = \int_0^n F(m)dm. \tag{3.7}$$

It then follows that the total revenue R to the provider is

$$R = R_u + R_v = p\left\{ F(q)q - \mathscr{F}(q) \right\} + p\left\{ 1 - F(q) \right\} q = p\left\{ q - \mathscr{F}(q) \right\}. \tag{3.8}$$

Note that the total revenue $R = R(q)$ is always positive, since $q > \mathscr{F}(q)$ for all q (See Figure 3.3C). We make the following calculation for later use.

$$R'(q) = p\left\{ 1 - F(q) \right\} > 0, \tag{3.9}$$

$$R''(q) = -pf(q) < 0, \qquad \text{for all } 0 \leqq q \leqq \bar{n}, \tag{3.10}$$

$$R(0) = 0, \quad \text{and} \tag{3.11}$$

$$R(\bar{n}) = p\left\{ \bar{n} - \mathscr{F}(\bar{n}) \right\} > 0. \tag{3.12}$$

Observe that the graph of R(q) has the shape shown in Figure 3. It is an increasing function for all q; its maximum takes pace at $q = \bar{n}$. This is what it should be, since, with the inelastic demand and without the cost of services, it is always advantageous for the provider not to offer private services.

We next proceed to consider the cost of public and private networks. For simplification, we will deal only with the case in which the construction and connection of all cables has been completed; when a subscriber pair switches from public to private services, or vice versa, no construction of cables needs to be made. The only difference between public services and private services lies in whether the pair is connected through switching machines or directly by shortcut circuits. Thus, the cost of cables is irrelevant for our analysis; we will assume it away completely.

Let c_u be the cost for the provider to serve a call with the public network (i.e., c_u is the unit switching cost), and c_v be the cost for the provider to offer a private connection (i.e., c_v is the unit cost of shortcut circuits). Then, the cost of the public network C_u and the cost of the private network C_v, respectively, can be written as

$$C_u = \int_0^q c_u n f(n) dn = \Big[F(n) c_u n \Big]_0^q - \int_0^q c_u F(n) dn = c_u \Big\{ F(q)q - \mathscr{F}(q) \Big\}, \quad (3.13)$$

and

$$C_v = \int_q^{\overline{n}} c_v f(n) dn = c_v \Big\{ 1 - F(q) \Big\}. \quad (3.14)$$

Thus, the total cost $C = C(q)$ to the provider is

$$C(q) = C_u + C_v = c_u \Big\{ F(q)q - \mathscr{F}(q) \Big\} + c_v \Big\{ 1 - F(q) \Big\}. \quad (3.15)$$

It will be convenient for us to calculate the following relations:

$$C(0) = c_v > 0, \quad (3.16)$$

$$C(\overline{n}) = c_u(\overline{n} - \mathscr{F}(\overline{n})) > 0, \quad (3.17)$$

$$C'(q) = c_u \Big\{ f(q)q + F(q) - F(q) \Big\} - c_v f(q) = \Big\{ c_u q - c_v \Big\} f(q), \quad (3.18)$$

$$C'(0) = -c_v f(0) < 0, \tag{3.19}$$

$$C'(\bar{n}) = (c_u \bar{n} - c_v) f(\bar{n}), \tag{3.20}$$

$$C''(q) = c_u f(q) + \left\{ c_u q - c_v \right\} f'(q), \tag{3.21}$$

$$C''(q) \Big|_{C'(q)=0} = c_u f(q) > 0. \tag{3.22}$$

The foregoing inequalities show that the graph of the total cost $C(q)$ is as typically depicted in Figure 3.4. Observe that the second derivative $C''(q)$ is negative whenever the first derivative vanishes. Therefore, local minimum (if it exits) is unique. It is evident that local minimum cannot take place at $q = 0$. It may occur at $q = \bar{n}$, if $c_u \bar{n} - c_v \leqq 0$, but this is the condition stating that the private network does not pay technologically even for the pair making the largest number of calls per day, an uninteresting case. We will thus assume that

$$c_u \bar{n} > c_v. \tag{3.24}$$

Then, the minimum of $C(q)$ exists uniquely at, say, $q = q^{**}$ and satisfies $C'(q^{**}) = 0$.

With the framework introduced above, it is possible to consider alternative principles which determine the relative price q. We first derive the implications of the provider's choosing a relative price $q = q^*$ so as to maximize the total profit. It is not unlikely to assume that the provider maximizes its profit even under governmental regulation, which is usually strict in determining the *absolute* price level p, for the level of p directly affects the distribution of income between the provider and the users. In many cases, it is not so much of the regulator's concern to maintain balance between the price of public services and the price of private services.

Let $\Pi = \Pi(q) = R(q) - C(q)$ be the total profit to the provider. Then, it follows from (3.8) and (3.15) that

$$\Pi(q) = p\left\{ q - \mathscr{F}(q) \right\} - c_u \left\{ F(q)q - \mathscr{F}(q) \right\} - c_v \left\{ 1 - F(q) \right\}, \tag{3.25}$$

$$= pq + \left\{ -c_u q + c_v \right\} F(q) + \left\{ -p + c_u \right\} \mathscr{F}(q) - c_v. \tag{3.26}$$

From this, we derive

$$\Pi(0) = -c_v < 0, \tag{3.27}$$

$$\Pi(\overline{n}) = (p - c_u)\overline{n} + (-p + c_u)\ \mathscr{F}(\overline{n}) \tag{3.28}$$

$$= (p - c_u)\ (\overline{n} - \mathscr{F}(\overline{n})) > 0, \quad \text{if } p > c_u, \tag{3.29}$$

$$\Pi'(q) = p - c_u\ (f(q)q + F(q)) + c_v f(q) + (-p + c_u)F(q) \tag{3.30}$$

$$= p(1 - F(q)) + (-c_u q + c_v)f(q), \tag{3.31}$$

$$\Pi'(0) = p > 0, \tag{3.32}$$

$$\Pi'(\overline{n}) = (-c_u\overline{n} + c_v)f(\overline{n}) < 0, \quad \text{if } \overline{n} > c_v/c_u, \tag{3.33}$$

$$\Pi''(q) = -pf(q) + (-c_u f(q)) + (-c_u q + c_v)f'(q), \quad \text{and} \tag{3.34}$$

$$= -(p + c_u)f(q) + (-c_u q + c_v)f'(q). \tag{3.35}$$

The above inequalities show that if we assume, as before, that $\bar{n} > c_v/c_u$, interior maximum of the total profit $\Pi(q)$ exists. Since we cannot sign $\Pi''(q)$, the possibility of multiple internal maxima cannot be excluded (See Figure 3.5).

The second principle to choose a price ratio q is the efficiency. For the present case, since we assume that the demand for telecommunication services, f(n) is given and fixed. Therefore, efficient allocation of resources implies minimization of the total cost $C(q)$. As seen before, this is achieved at the relative price $q = q^{**}$.

A question then arises whether the profit maximizing relative price q^* is greater, or less, than the efficient relative price q^{**}. We can immediately provide a definite answer to it:

Proposition: *The profit maximizing relative price q^* is always greater than the efficient relative price q^{**}.*

Proving this proposition is straightforward. We only need to evaluate the first derivative of $C'(q)$ at $q = q^*$:

$$C'(q^*) = p(1 - F(q^*)) > 0, \tag{3.36}$$

in view of (3.18) and (3.31) with $\Pi'(q^*) = 0$. Thus, the only possible case is the one shown in Figure 3.6, in which the only possible relation is $q^{**} < q^*$. Also see Figure 3.7.

In order to examine the behavior of NTT with regard to pricing public and private services, we calculated data shown in Table 3.1. The average price p of public services is a weighted average of the charge for a call of 100km and a call exceeding 320km, both for daytime on weekdays. The average price of private services is the average of the price of lines for voice–level 120km, for 3.4KHz 120km, for 3.4KHz 1000km, and for 9600b/s 120km. It is shown that the relative price q increased during the period of 1985 to 1990, the five–year period after the privatization of NTT. We also calculated the ratio of the unit cost (cv) of private services to the unit cost (cu) of public services, which also increased during this period. The ratio of the relative price q to the cost ratio, cv/cu, however, is found to have decreased from 1985 to 1990. Thus, we may assert that if the actual relative price q exceeded the cost–minimizing relative price ($q^{**} = cv/cu$), then the discrepancy between the two was narrowed down during the five–year period, implying an improved efficiency in NTT's operation of public and private networks.

VI. Comparison of Public vs. Private Networks of NTT: 1985 – 1990

This section reports the results of our calculation to estimate the total factor productivity (TFP) of the public and the private networks of NTT. A fundamental assumption for this work is to consider the public network and the private network as separate entities. (In reality, this is not true, because capital, labor, and other resources of NTT are shared by the two networks.) NTT has published data of operating costs attributed to each of the services it supplies, in which public services and private line services are included. Further, data of new investment in capital equipment for public and private networks are also available from NTT. Calculation of TFP of the two networks became possible with these data.

The published cost data, however, do not distinguish labor cost from other costs. To calculate TFP according to a standard procedure, we split the cost data of the two networks into labor and other costs in the same proportion that the total cost of NTT is split into labor and other costs. Since the public network operation is approximately 90% of the entire operation in NTT, this means that we would overlook, for example, an effort taking place in the private network to save the labor cost, if there was such effort. Further, data on investment in telecommunications equipment are not divided into switching machines, cables, etc. We, therefore, treated the capital stock in the two networks as homogeneous. This is not true in reality, because the private network does not use switching machines. Aside from the drawbacks of our analysis mentioned in this paragraph, our work follows by and large a standard procedure to calculate TFP.

Tables 4.1 through 4.5 report our findings on TFP of the public and the private networks of NTT for the five-year period from 1985 to 1990. (See also Figures 4.1 – 4.8.) In the public network, the output index and the input index increased respectively by 48% and 10% for the five years (8.01% and 1.89% annually, respectively). Consequently, TFP increased by 34.4% for the five years (6.09% annually).

For the private network, the growth of TFP is not as remarkable as in the public network. It grew 20.5% for the five years (3.8% annually). Output grew very fast at an annual rate of 13.6% but the input also grew at a high rate of 9.5% annually for the five years. One may comment that TFP of the public network is overestimated because of the choice of the price index, which is a weighted average of the price for a 100km call and the price for a call exceeding 320km.

By means of partial factor productivity (PFP) reported in Table 4.3, one can divide TFP into the three input components, capital, materials–services, and labor. For the public network, the largest contribution to the increase in TFP comes from labor productivity with 20.4% growth for the five years. On the other hand, TFP of the private network was held back by an insignificant contribution of materials–services, with which PFP is almost nil.

[Efficiency] *TABLE 3.1*

Year	Average Price of Public Service (p)	Average Price of Private Service (Q)	Q/p=q	Revenue Public Service (RU)
1985	213.1	235.00	1.10	4,233,722
1986	213.1	235.00	1.10	4,368,894
1987	201.1	222.50	1.11	4,553,766
1988	191.2	222.50	1.16	4,625,365
1989	176.2	197.25	1.12	4,727,197
1990	165.1	192.25	1.16	4,841,587
	P4	P9	P9/P4=[5]	R2

Year	Revenue Private Service (RV)	Cost Public Service (CU)	Cost Private Service (CV)	RU/CU
1985	251,408	3,665,156	147,439	1.16
1986	275,167	3,818,808	171,030	1.14
1987	295,405	3,961,645	194,955	1.15
1988	346,513	4,148,117	241,413	1.12
1989	372,036	4,296,472	271,315	1.10
1990	389,782	4,502,311	300,093	1.08
	R3	C2	C3	R2/C2

Year	RV/CV	MU=RU/PU	MV=RV/PV	cu=CU/MU
1985	1.71	19867.30	1069.82	184.48
1986	1.61	20501.61	1170.92	186.27
1987	1.52	22644.29	1327.66	174.95
1988	1.44	24191.24	1557.36	171.47
1989	1.37	26828.59	1886.11	160.15
1990	1.30	29325.18	2027.47	153.53
	R3/C3	[1]=R2/P4	[2]=R3/P9	C2/[1]=[3]

Year	cv=CV/MV	cv/cu	q/(cv/cu)
1985	137.82	0.75	1.48
1986	146.06	0.78	1.41
1987	146.84	0.84	1.32
1988	155.01	0.90	1.29
1989	143.85	0.90	1.25
1990	148.01	0.96	1.21
	C3/[2]=[4]	[6]=[4]/[3]	[5]/[6]

Table 4.1 TFP, Output Index, and Input Index
Public Network, NTT (1985-1990)

	TFPU	OUTPUTQU	INPUTQU
1985	1.000	1.000	1.000
1986	1.025	1.032	1.007
1987	1.117	1.140	1.021
1988	1.158	1.218	1.052
1989	1.268	1.350	1.065
1990	1.344	1.476	1.098

Table 4.2 TFP, Output Index, and Input Index
Private Network, NTT (1985-1990)

	TFPV	OUTPUTQV	INPUTQV
1985	1.000	1.000	1.000
1986	1.006	1.095	1.088
1987	1.058	1.241	1.173
1988	1.062	1.456	1.371
1989	1.199	1.763	1.471
1990	1.205	1.895	1.573

Table 4.3 TFP and PFP
Public and Private Networks, NTT (1985-1990)

	TFPU	PFPKU	PFPMU	PFPLU	TFPV	PFPKV	PFPMV	PFPLV
1985	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1986	1.02	1.00	1.01	1.08	1.01	1.06	0.96	1.03
1987	1.12	1.04	1.06	1.33	1.06	1.14	0.94	1.18
1988	1.16	1.06	1.11	1.40	1.06	1.31	0.91	1.15
1989	1.27	1.11	1.21	1.60	1.20	1.54	1.00	1.33
1990	1.34	1.13	1.28	1.79	1.20	1.54	0.99	1.39

Table 4.4 Input Indices
Public and Private Networks, NTT (1985-1990)

	NKU	NMU	NLU	NKV	NMV	NLV
1985	1.00	1.00	1.00	1.00	1.00	1.00
1986	1.03	1.02	0.95	1.04	1.14	1.06
1987	1.09	1.08	0.86	1.09	1.32	1.05
1988	1.15	1.10	0.87	1.11	1.59	1.26
1989	1.21	1.12	0.84	1.14	1.75	1.32
1990	1.30	1.16	0.82	1.23	1.92	1.37

Table 4.5 Input Shares
Public and Private Networks, NTT (1985-1990)

	SKU	SMU	SLU	SKV	SMV	SLV
1985	0.33	0.40	0.27	0.25	0.45	0.30
1986	0.37	0.37	0.25	0.29	0.43	0.29
1987	0.33	0.41	0.26	0.22	0.47	0.30
1988	0.28	0.43	0.29	0.15	0.51	0.34
1989	0.30	0.42	0.28	0.15	0.51	0.34
1990	0.37	0.38	0.25	0.20	0.48	0.32

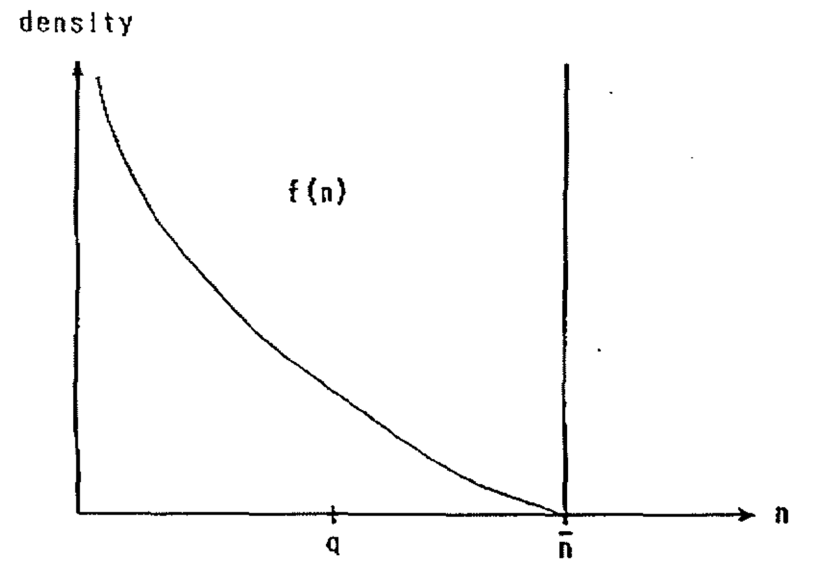


Fig. 3.1

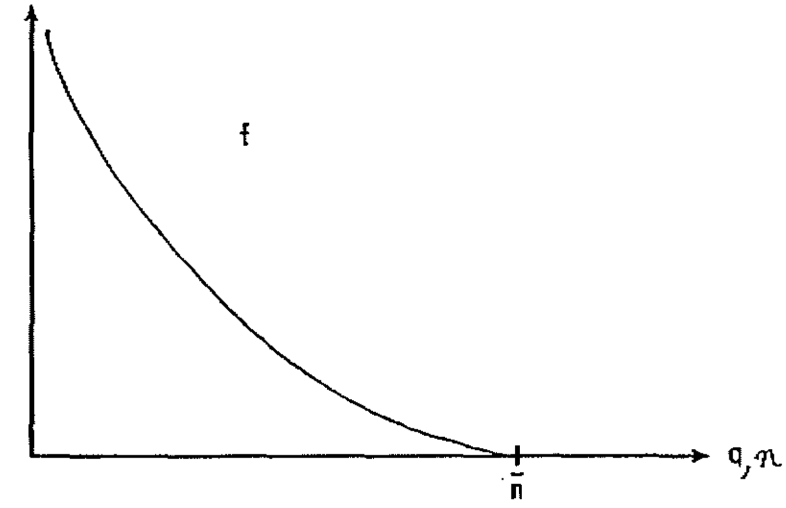


Fig. 3.2A

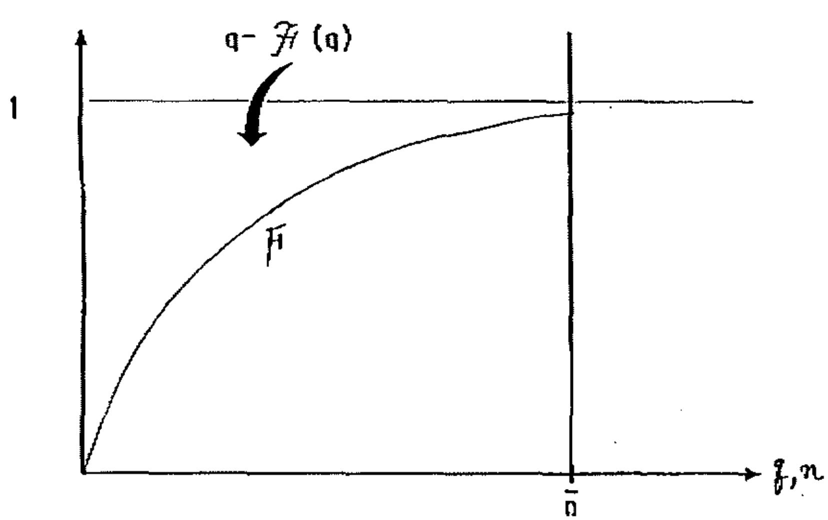


Fig. 3.2B

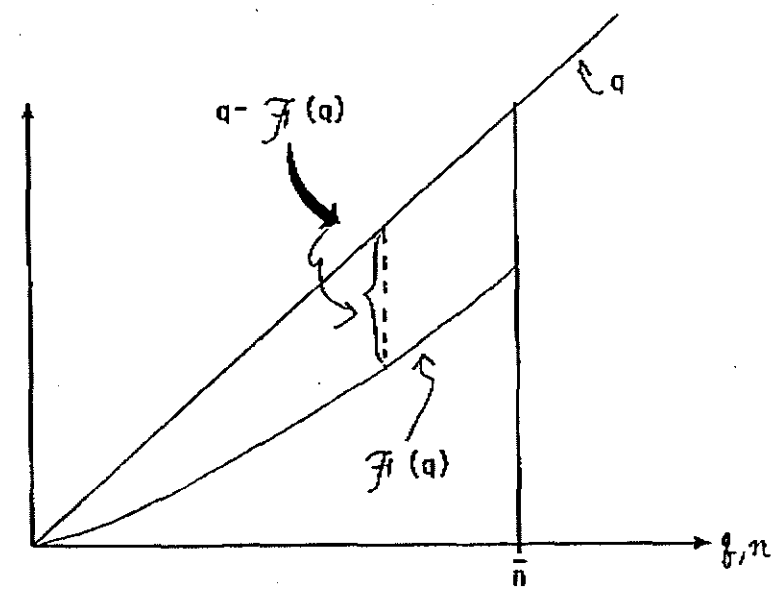


Fig. 3.2C

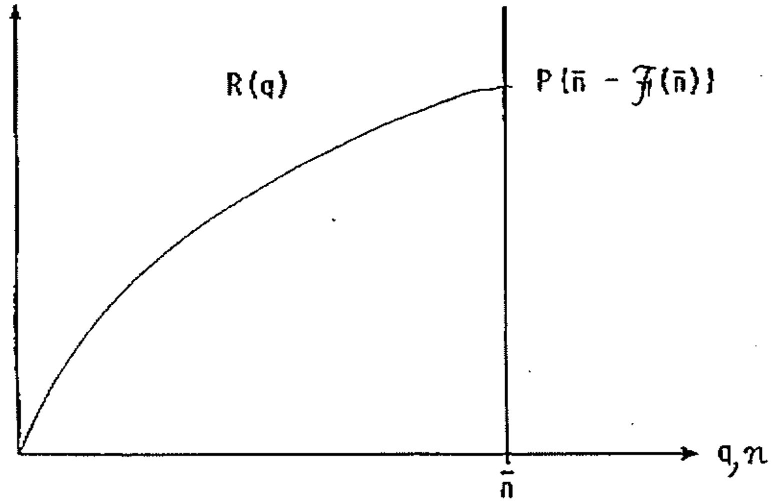


Fig. 3.3

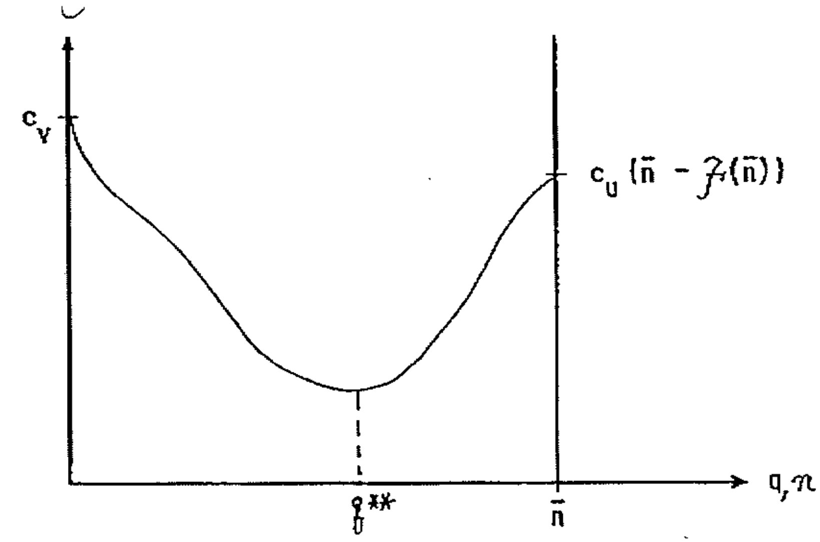


Fig. 3.4

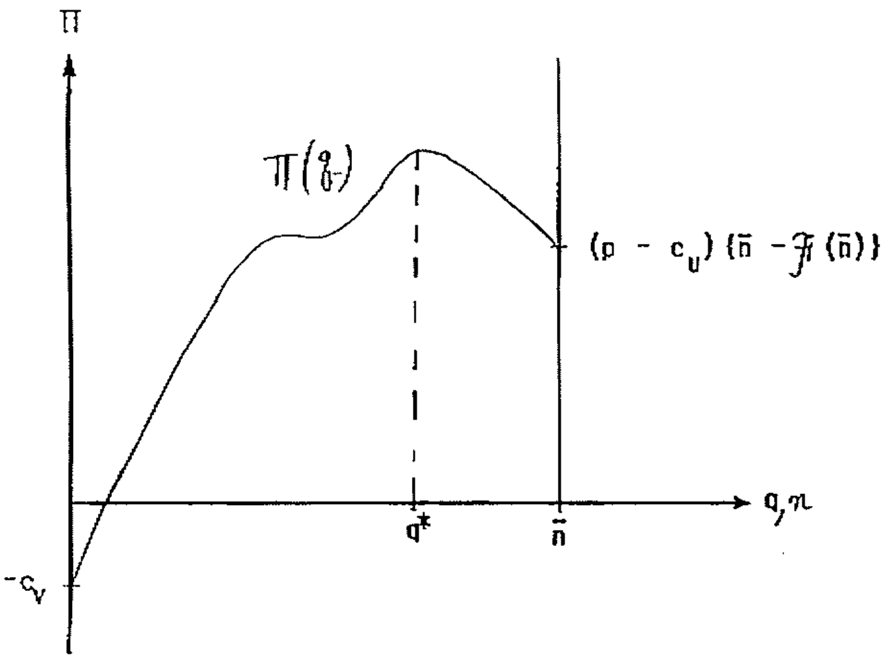


Fig. 3.5

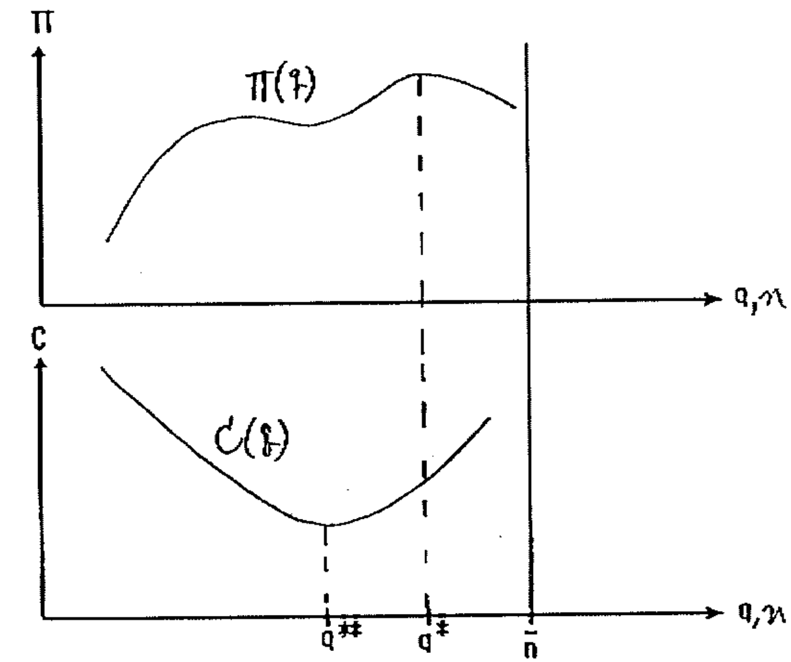
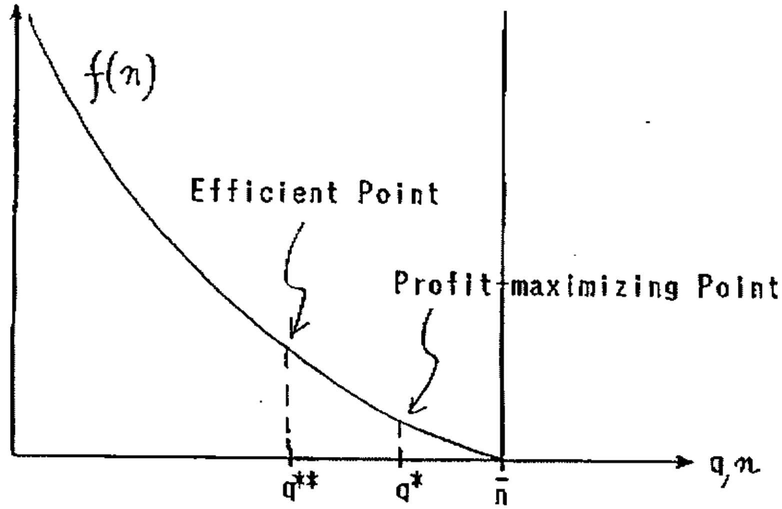


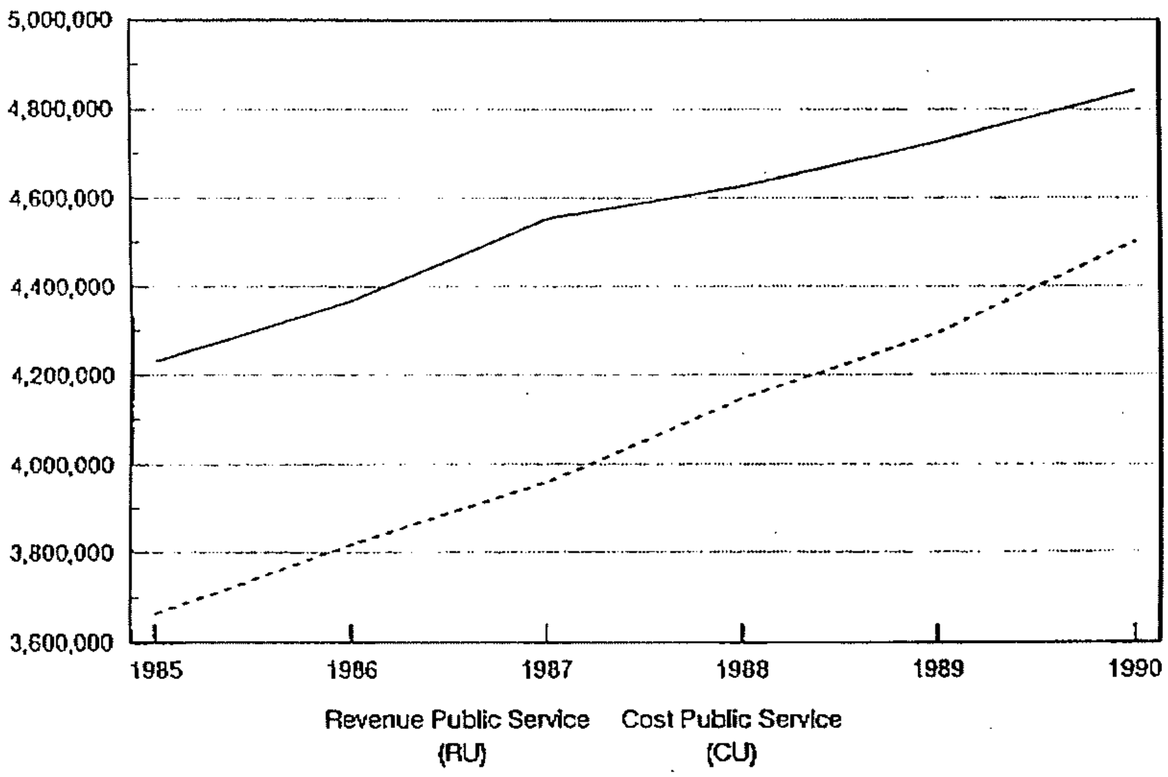
Fig. 3.6



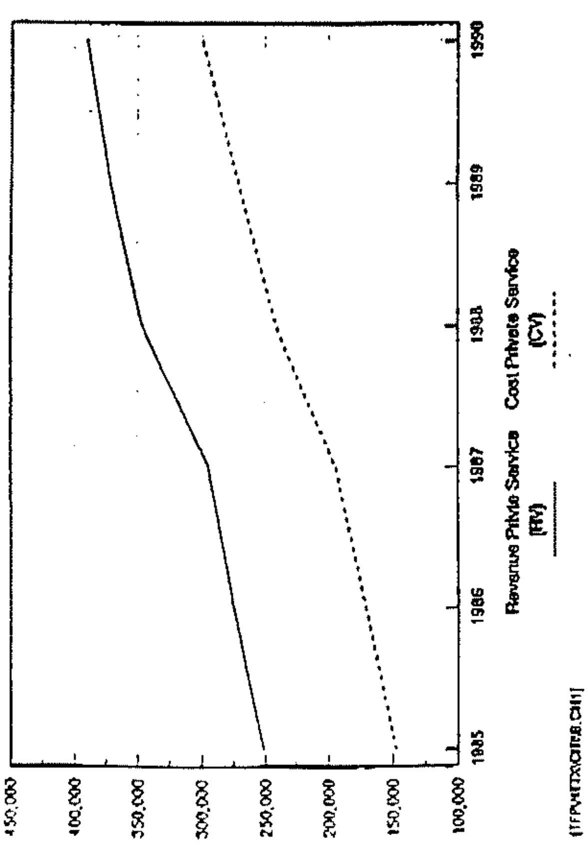
f(n)
Efficient Point
Profit-maximizing Point
q**
q*
n̄
q, n

Fig. 3.7

Fig. 3.8



5,000,000
4,800,000
4,600,000
4,400,000
4,200,000
4,000,000
3,800,000
3,600,000
1985
1986
1987
1988
1989
1990
Revenue Public Service (RU)
Cost Public Service (CU)



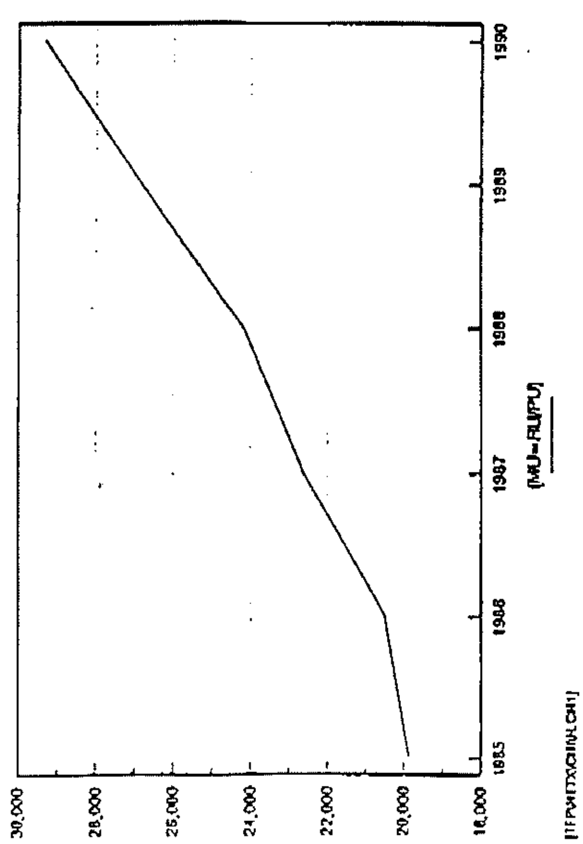
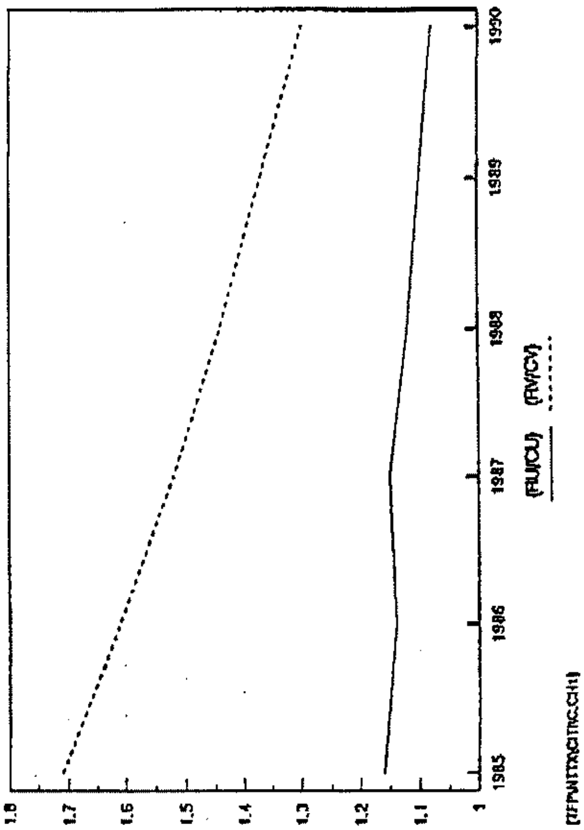


Fig. 3.11



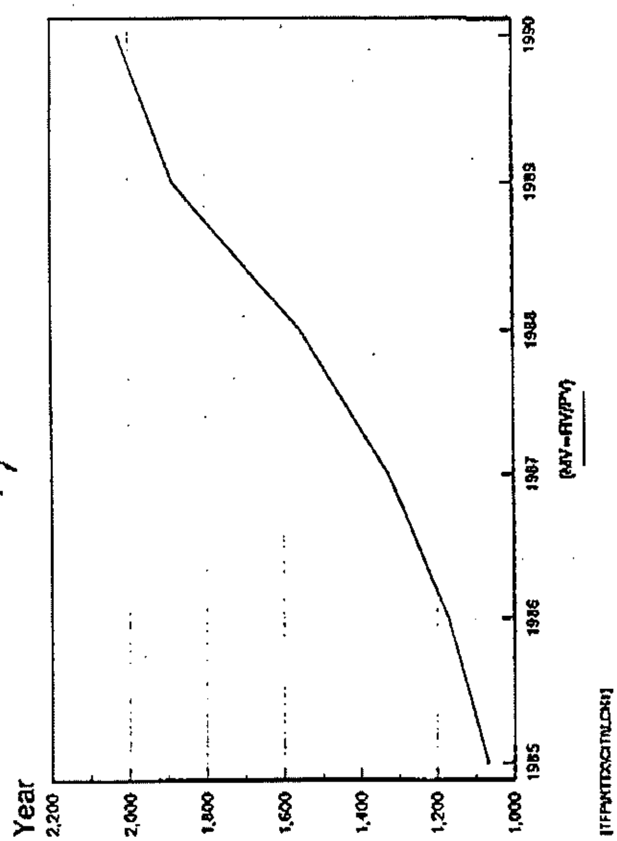
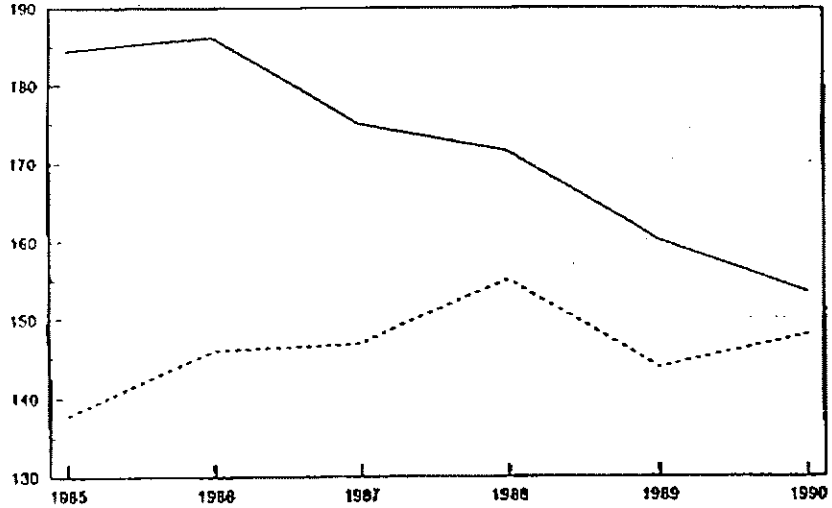
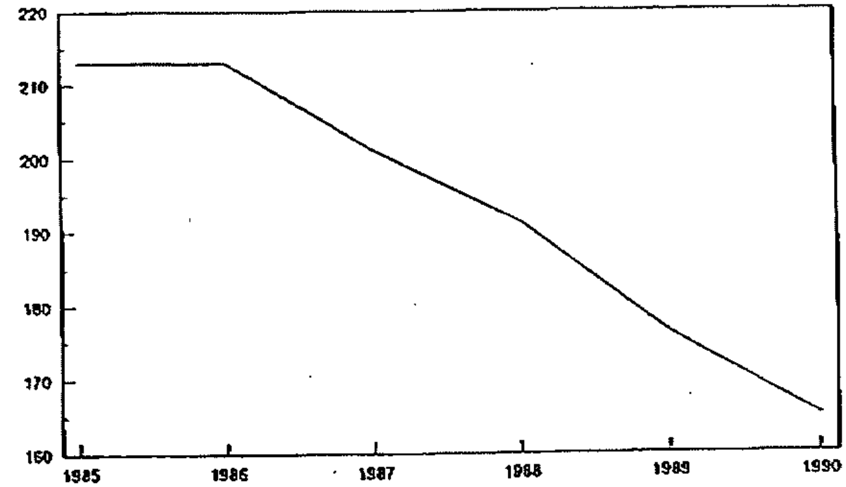


Fig. 3.12



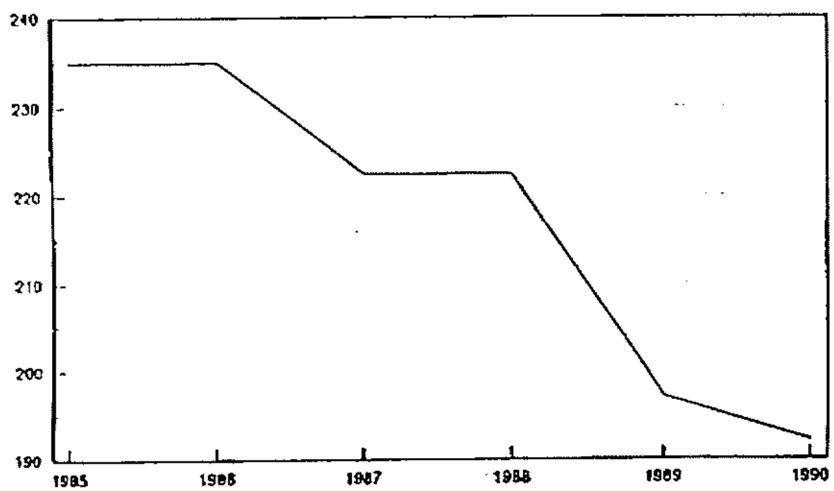
(CU/MU) (CV/MV)

Fig. 3.15

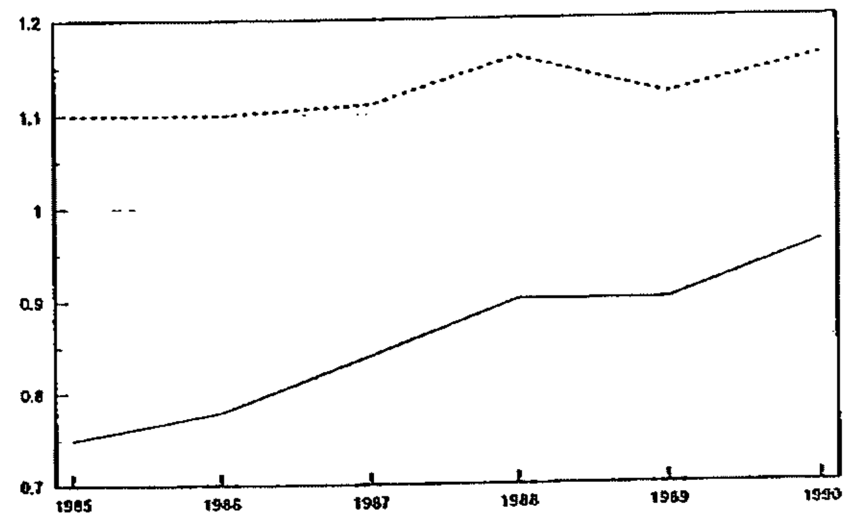


Average Price of Public Service
(p)

Fig. 3.16



Average Price of Private Service
(Q)



(cv/cu) (Q/p-q)

Fig. 3.17

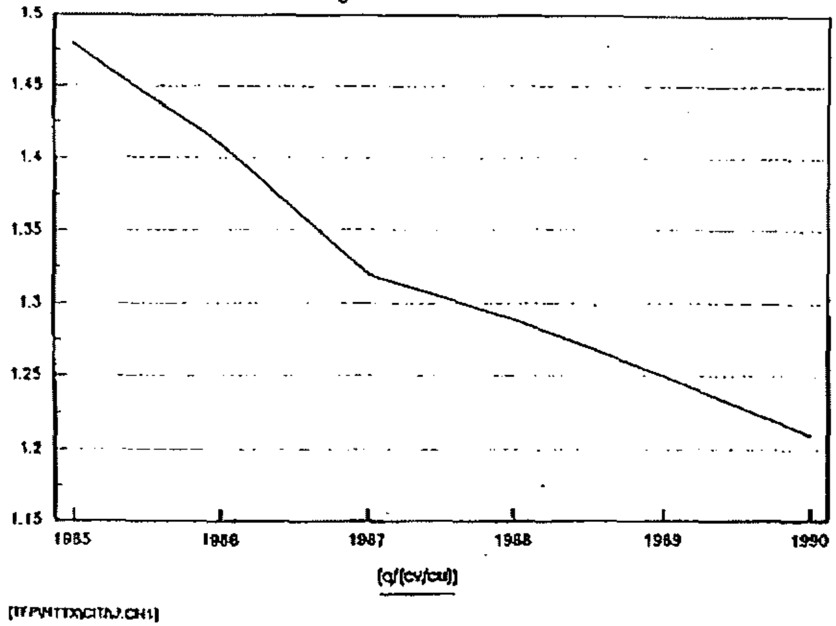


Fig 4.1
TFP, Output Index, and Input Index
Public Network, NTT (1985-1990)

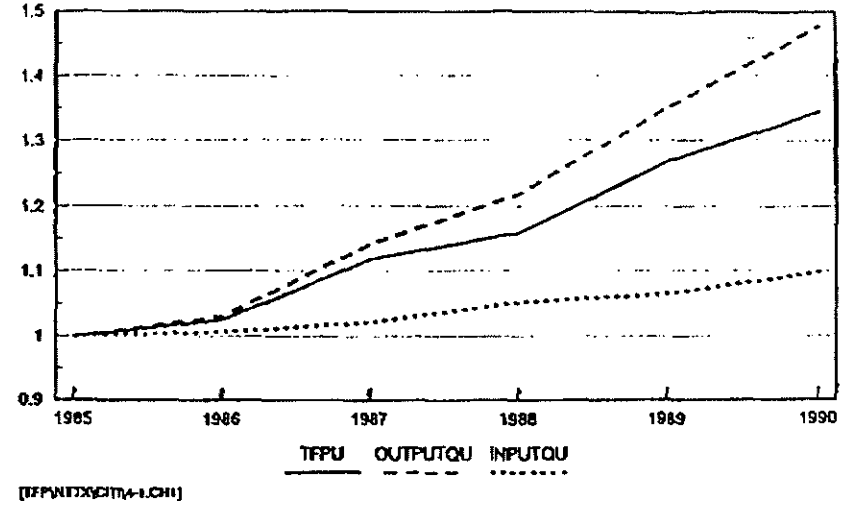


Fig 4.2
TFP, Output Index, and Input Index
Private Network, NTT (1985-1990)

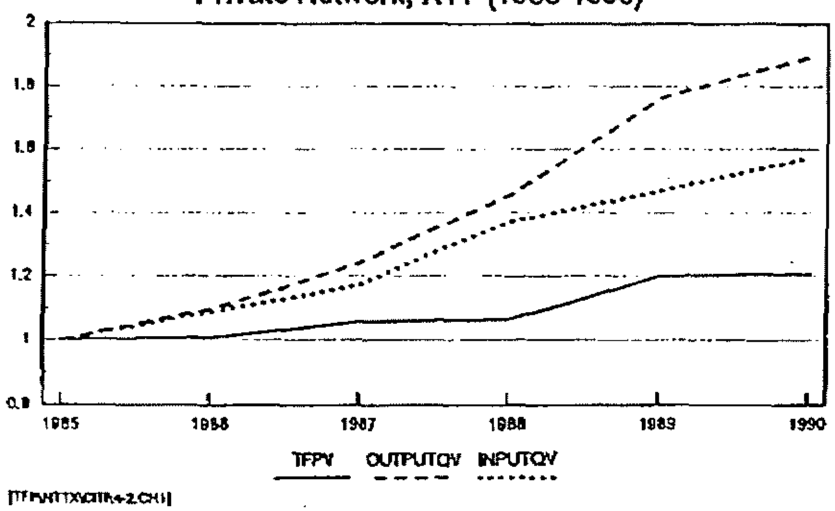


Fig 4.3
TFP and PFP
Public Network, NTT (1985-1990)

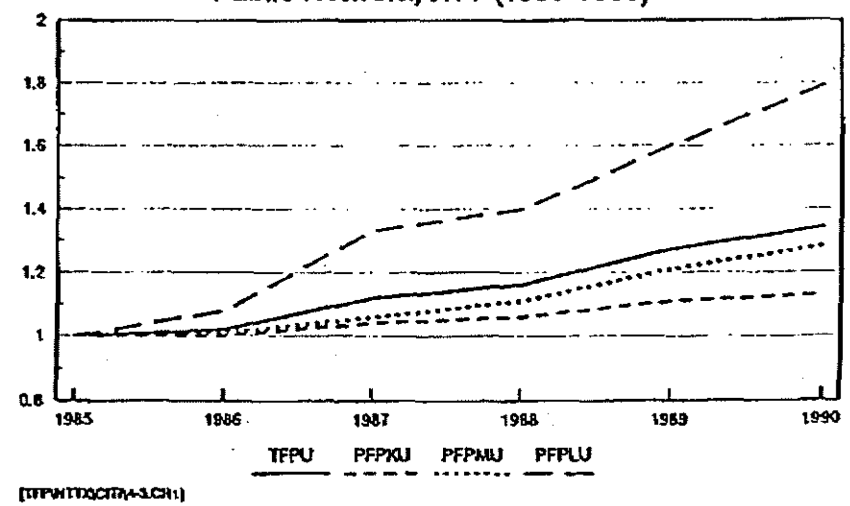
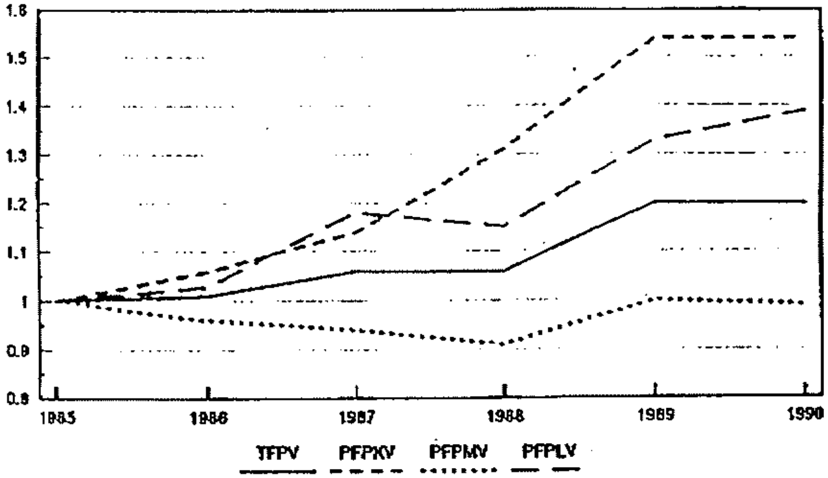
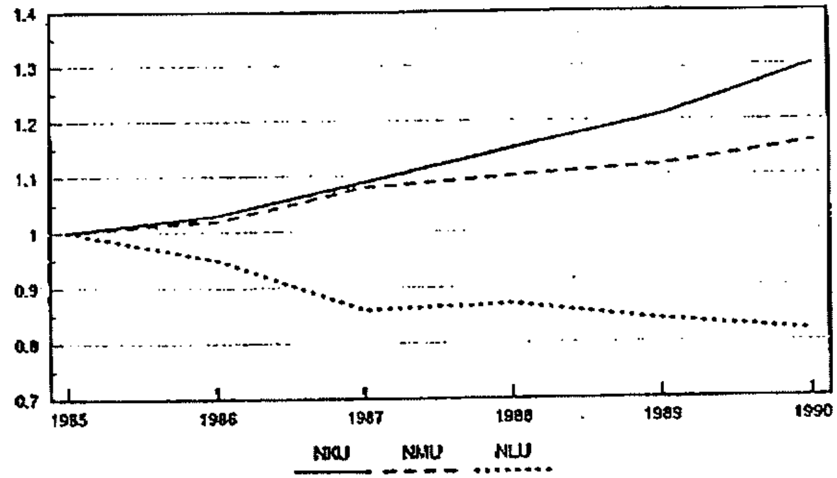


Fig 4.4
TFP and PFP
Private Network, NTT (1985-1990)



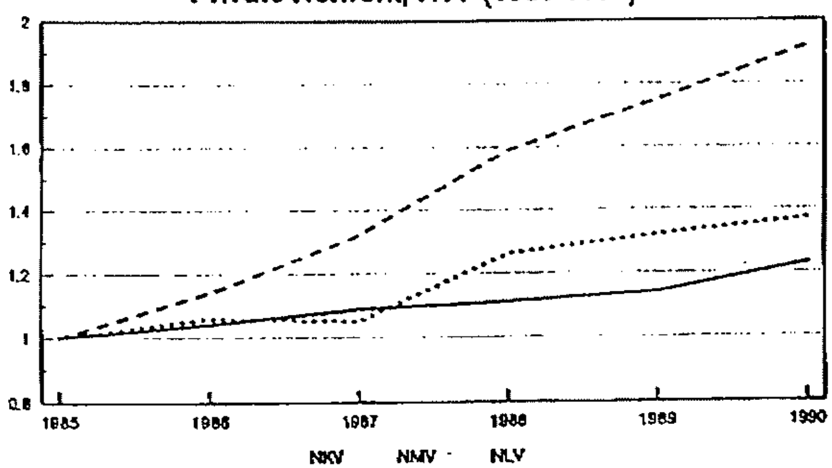
[TFP\NTTX\CITN4-4.CH1]

Fig 4.5
Input Indices
Public Network, NTT (1985-1990)



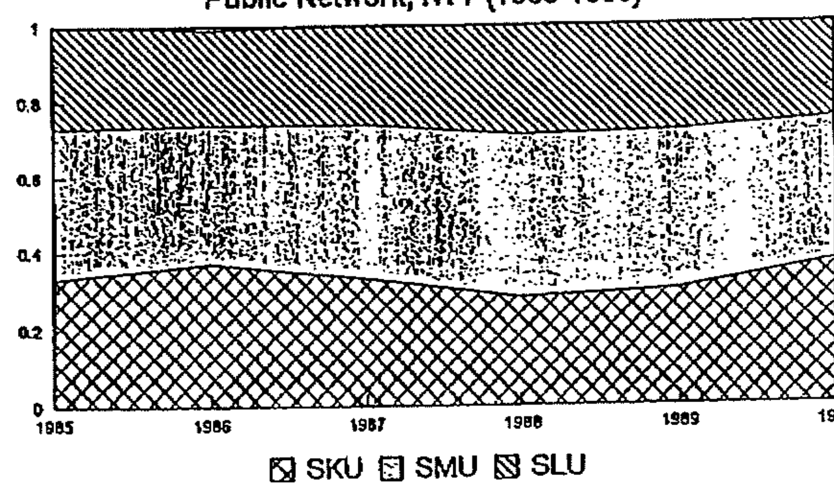
[TFP\NTTX\CITN4-5.CH1]

Fig 4.6
Input Indices
Private Network, NTT (1985-1990)



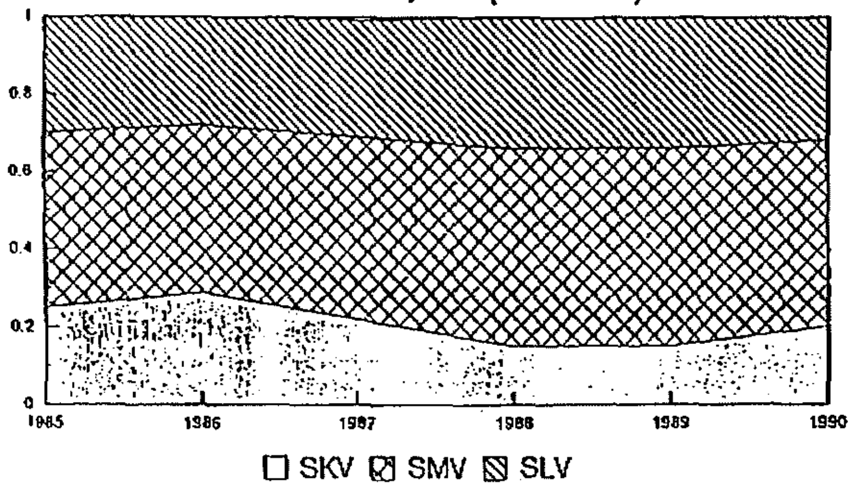
[TFP\NTTX\CITN4-6.CH1]

Fig 4.7
Input Shares
Public Network, NTT (1985-1990)



[TFP\NTTX\CITN4-7.CH1]

Fig 4.8
Input Shares
Private Network, NTT (1985-1990)



Notations:

U: public network

V: private network

Q: quantity

P: price

R: revenue

C: cost

Y: output

K: capital

M: materials

L: labor

S: share

N: normalized