Why Do Governments Encourage Improvements in Infrastructure? Indirect Network Externality of Transaction Efficiency

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Abstract
Governments have been very active in engaging in and in encouraging the improvements in transaction efficiency, including the provision of legal, social, and economic infrastructures. While this may partly be explained by the public goods nature, the presence of indirect network externalities due to the economies of specialization may also be important. The improvement in transaction (including communication and transportation) efficiency may generate benefits in excess of the direct private benefits through the promotion of higher degree of specialization. This is shown in the Yang-Ng framework of inframarginal analysis.

Keywords: externality, infrastructure, networks, public capital, specialization, transaction efficiency.

JEL classifications: D23, D62, H23.
1. Why do governments encourage improvements in transaction efficiency?
Governments have been very active in engaging in and in encouraging the improvements in transaction efficiency, including the provision of legal, social, and economic infrastructures. (For the effects of infrastructure on productivity, see World bank 1994 for a survey; see also Boserup 1981 and Chandler 1990 on the historical perspective and the importance of population size.) Even free-market economists including Adam Smith find ‘the erection and maintenance of the public works which facilitate the commerce of any country, such as good roads, bridges, navigable canals, harbours, &c’ desirable and indeed find this as ‘evident without any proof’ (Smith 1776/1976, II, p.245). Perhaps this apparently self-evident nature made economists pay little attention to the role of infrastructure in either theoretical or empirical studies until the late 1980’s when Aschauer (1989) started to attract interest. (See Gramlich 1994 for a survey.) This interest is mainly concerned with the relationship of infrastructure investment and economic growth or the related issue of the productivity of public capital (e.g. Bougheas, Demetriades & Mamuneas 2000, Day & Zou 1994, Easterly 1993, Evans & Karras 1994, Holtz-Eakin 1994, La Ferrara 2001). While these issues are also related to the theme of this paper, the latter is more concerned with the specific point as to the reasons why the involvement of the government is needed.

The need for government involvement may be explained by the public goods nature of infrastructure. This may well be the major part of the explanation for many cases. However, if this is the only reason, there is little reason for encouragement if the items involved are excludable and can be priced as applicable in many cases including communications. Moreover, according to the traditional analysis, even for non-excludable items, there should be no reason for providing them beyond the levels indicated by the equation of (aggregate) marginal benefits and marginal costs, evaluated at the existing structure of economic organizations or the degree of specialization of the whole economy (which is not taken as a variable in the traditional analysis). In this paper, it is argued that, if we take the degree of
specialization as endogenous, the provision of infrastructures that decreases transaction costs may produce some indirect network externality. This should be distinguished from the possible network externality of the infrastructure itself, which is well known. For example, the usefulness of a telephone, fax machines, email facility increases as more people are on the phone, etc. This is the direct network externality, which we shall abstract away. Rather, we refer to the following more indirect effects.

The improvement in transaction (including communication and transportation) efficiency may generate benefits in excess of the direct private benefits through the promotion of higher degree of specialization. If transaction efficiency is very low (i.e. transaction costs are very high), it may be optimal for everyone to be in autarky, self-producing all goods needed. As transaction efficiency improves, it may becomes optimal to buy some goods from others and sell the good one specializes in, but in general still have some goods self-produced and self-consumed (which exist even in modern times, including home cooking, cleaning, and gardening). As transaction efficiency improves, the set of goods bought from others increases. Thus, the benefits of an improvement in transaction efficiency is not only directly in reducing the costs of transaction, but also in indirectly promoting the degree of specialization and the consequent tapping of the economies of specialization. Even assuming that the costs of exclusion is negligible and that there is no free-rider problem, a private producer of an improvement in infrastructure that reduces transaction costs may only be able to capture the direct benefits of lowering transaction costs, but not be able to capture the indirect benefits of promoting more specialization (even in the absence of individual differences giving rise to different consumer surpluses). People will just assess the benefits of lower transaction costs given the existing level of specialization of the economy. Not only that the benefits through a higher degree of specialization will occur only in the future contingent on the appearance of new marketable goods, but also this development is taken as not affected by the improvement in the transaction efficiency of an individual herself. It is
thus rational even under full knowledge to ignore the indirect benefit of higher transaction efficiency on the level of specialization. In other words, there are two public-good problems. The improvement in infrastructure to raise transaction efficiency may itself be a public good. However, even if this public-good problem can be overcome through excludability, there is another public-good problem at the level of the increase in the level of specialization that the higher transaction efficiency contributes to. Even with perfect foresight, each individual does not take into account the benefits of a higher level of specialization because that level is determined by the general level of transaction efficiency prevailing in the whole economy, not appreciably affected by that of the individual. Even if, especially after writing this paper, we correctly foresee that the widespread use of a new communication system will promote specialization and make a number of new products available in the market, we will not count the benefits of the availability of the new products in assessing the usefulness of the new communication system to us, as the new products will be available even if we do not use the new communication system but if others do. This second level of publicness problem is quite impossible to solve through exclusion, as the producers of the new set of products are typically different from the producer of the infrastructure. Thus, the indirect externality of infrastructure may then make the public provision or encouragement desirable. The Yang-Ng framework of inframarginal analysis is used in the next section to analyse the case for encouraging improvement in transaction efficiency over and above its direct benefits.1 Our results are consistent with the empirical evidence that public infrastructure capital has positive long-run effects on output and that ‘the short-run rates of return are rather low while the long-run rates of return tend to be quite high’ (Demetriades & Mamuneas 2000, p. 689). It takes time for the degree of specialization to develop.

In the demonstration, we also discovered that the lumpiness in investments to improve transaction efficiency also play a role in creating a divergence between social and private benefits. For non-lumpy investments, the divergence is negligible. This may also partly explain why big projects may be regarded as a ground for
encouragement. Of course, like all other reasonable justification, this one may also be misused to justify really inefficient projects.

2. A perspective from the Yang-Ng framework

The Neoclassical economists made an important analytical advance by introducing marginal analysis into economics, with the use of the powerful tool of calculus. This allows problems of resource allocation to be analysed rigorously, with many important results. This concentration on resource allocation problems using calculus has been facilitated by the dichotomy of consumers and producers. It also diverted the attention of economists from the equally important problems of division of labour, economies of specialization, and economic organization that were emphasized by classical economists including Adam Smith. Yang & Ng (1993) "attempt to shift the focus back to specialization and the division of labor by abandoning the dichotomy between consumers and producers... [and] have provided us with a refreshing new approach to microeconomics, one that has the potential to address many issues that have long resisted formal treatments" (Smythe 1994, p.692). Abandoning the dichotomy allows the choice of economic organizations (autarky, trade, firms, hierarchy) to be analysed endogenously from the basic decisions at the individual level.

In contrast to the above-mentioned modelling of specialization at the individual level (detailed below), the earlier papers of Ethier (1982) and Romer (1987) takes the output of a final good as a function of intermediate inputs more of which increases productivity but for the fixed costs of their production. Specialization increases the number of intermediate inputs and may increase productivity but this has to be traded off with the fixed costs. Bougheas, Demetriades & Mamuneas (2000) extends Romer's model to allow a role for infrastructure by assuming that "the fixed costs of producing intermediate inputs vary inversely with the stock of public capital relative to the size of the economy" (p.509, italics original). The resource costs of the public capital may then make the relationship between
infrastructure and growth an inverted U-shaped one, as supported by the empirical evidence presented. In contrast, the analysis below allows a role for infrastructure by letting it affect the transaction efficiency. Different modellings and different focuses of the same issue may throw different but all useful perspectives.

Partly for simplicity and partly to show the non-reliance on exogenous heterogeneity of individuals (and the resulting exogenous comparative advantages), Yang and Ng assume that the economy consists of M ex-ante identical consumer-producers and m consumer goods. Denoting the self-provided amount of good i as $x_i^s$, the amount purchased from the market of good i as $x_i^d$, the amount of good i consumed is $x_i + k x_i^d$, where $k x_i^d$ is the amount an individual obtains when she purchases $x_i^d$, 1 - $k$ being the transaction cost coefficient and $k$ the transaction efficiency coefficient.

A Cobb-Douglas utility function is adopted to reflect the preference for diverse consumption. (Other utility functions are also used in Yang & Ng 1993 without changing the main results. General utility functions and more general productions functions are used in the proof of existence of equilibrium in the Yang-Ng framework in Zhou, Sun & Yang 1998.)

\[ u = x_i \Pi_{R} k x_i^d \Pi_{J \neq i} x_j \]

where $x_i$ is the quantity of good i retained by individual i for self-consumption, $R_i$ is the set of goods purchased from other individuals, 1 - $k$ is the transaction costs of trade, and $J_i$ is the set of self-provided goods. Each consumer-producer also has a system of production functions,

\[ x_i + x_i^s = l_i^s \]
\[ x_j = l_j^s \forall j \in J_i \]

where $x_i^s$ is the amount of good i sold to the market and $x_i^s$ is the amount of good i produced and $l_i$ the amount of labour used in producing good i. The assumption of $a > 1$ captures the economies of specialization, making the labour productivity in the production of each good increase with the individual's level of specialization in its production, measured by the labour time used. Apart from the per unit transaction cost
(1-k), a fixed cost (measured by labour time) for the purchase of each good c is also assumed. The endowment constraint of the individual is given by

\[ c(n-1) + l_i + \sum_{j \neq i} l_j = 1 \]

where the total amount of labour time has been normalized to unity. The budget constraint of the individual is given by

\[ \sum_{i \in R} p_i x_i = \sum_{r \in R} \sum_{i \in R} P_r x_r \]

where \( p_i \) is the price of good i, \( R \) is a set of all goods purchased. In (4), only one good is supplied to the market by an individual since, from \( \alpha > 1 \), it can be shown that an individual sells only one good at most (See Lemma 2.1 in Yang and Ng, 1993). Each individual (effectively) takes the market prices as given either because the population is large relative to the number of goods and thus the number of individuals producing each good i, \( M_i \), is large and/or due to the coincidence with the Walrasian regime in the multilateral bargaining game of the Yang-Ng model (1993, Ch.3).

Each individual is then allowed to maximize utility by allotting her/his fixed amount of time to the production and purchase of different goods, balancing the tradeoff between economies of specialization \( \alpha > 1 \) on the one hand and the costs of market transaction \( (1-k) > 0, c > 0 \) on the other. Each individual is allowed not only to choose the quantities of the various goods consumed but also to choose what goods to self-provide and sell to the market. If an individual buys a good, she does not sell it and vice versa.

Next, market equilibrium in terms of the equality of the amount of each good supplied and demanded in the market is then imposed.

\[ M_i x_i = \sum_{r \in R} M_r x_{ri} \]

where \( M_i \) is the number of individuals selling good i, \( x_{ri} \) is the amount of traded good i purchased by individuals selling good r, it can then be shown that (Proposition 5.1 of Yang and Ng) if the transaction efficiency and/or the degree of economies of specialization are very low, the equilibrium is autarky. All individuals self-provide all
goods. As the transaction efficiency improves (i.e. $k$ increases), each individual sells a good to the market and buys some other goods in exchange. The number of goods purchased from the market, division of labour and income all increase with transaction efficiency.

The requirements of market equilibrium (5) and utility equalization to ensure a general equilibrium in the model of *ex-anti* identical individuals and symmetrical production functions for all goods ensure that all prices are equal and may be taken as unity. Thus, maximizing (1) subject to (2) - (4), we have (the detailed working is available from the authors)

\[
x_i = \left( \frac{[1-c(n-l)]}{m} \right)^a n^{a-1}
\]

(6)

\[
x_j = \left( \frac{[1-c(n-l)]}{m} \right)^a
\]

(7)

\[
u = \left( \frac{[1-c(n-l)]}{m} \right)^{2m} n^{(a-1)n} k^{n-1}
\]

(8)

From (8), it seems that the maximization of $u$ with respect to $n$ yields the optimal number of goods purchased. The optimal value $n^*$ is the integer in the neighbourhood of $n^{**}$ that is given by the first-order condition $\partial u/\partial n = 0$. (It is assumed that $c$ is of sufficient high value to ensure the satisfaction of the second-order condition.) This is in fact the case when everyone in the economy has adjusted to the given set of parametric values (particularly $k$, $c$, and $a$) with no further opportunity for improvement. However, when a parameter just changes its value, the desired adjustment of an individual is subject to the market opportunity at the time. For example, as the transaction efficiency coefficient $k$ increases, each individual may wish to increase the number of goods purchased from others. However, this desire may
not be realized before the additional marketable goods are supplied in the market. This problem is especially serious in a realistic model where goods are not symmetrical. Then, goods (that would have been purchased) may not be supplied in the market soon after an increase in transaction efficiency but before the organizational structure of the whole economy adjusts to the new situation. For example, with higher transaction efficiency, people may want to buy take-away meals and spend less time doing home cooking (a good in the set $J$) but may not be able to do so before some take-away meals are sold in the market. However, in time, some entrepreneurs will see the opportunity. For example, the MacDonald restaurant was launched with great success. This changes the structure of economic organization of the society and increases the degree of specialization. People can then spend less time doing home cooking and more on the specialized profession. However, before the new goods are offered for sale in the market, it is quite impossible that people (including firms) will take account of the specialization-enhancing effect through organizational changes of the whole society in assessing the benefits of higher transaction efficiency. Even assuming that the costs of exclusion is negligible and that there is no free-rider problem, a private producer of infrastructure that reduces transaction costs may not be able to capture the indirect benefits of promoting more specialization (even in the absence of individual differences giving rise to different consumer surpluses). People will just assess the benefits of lower transaction costs given the existing level of specialization of the economy. In the framework presented above, it means that people will assess the benefits of a higher $k$ or lower $c$ at given $n$. Not only that the benefits through a higher $n$ will occur only in the future contingent on the appearance of new marketable goods, but also this development is taken as not affected by the improvement in the transaction efficiency of each individual herself. It is thus rational even under full knowledge to ignore the indirect benefit of higher transaction efficiency on the level of specialization. In other words, there are two public-good problems. The improvement in infrastructure to raise transaction efficiency may itself be a public good. However, even if this public-good problem can be overcome through excludability, there is
another public-good problem at the level of the increase in the level of specialization that the higher transaction efficiency contributes to. Even with perfect foresight, each individual does not take into account the benefits of higher level of specialization because that level is determined by the general level of transaction efficiency prevailing in the whole economy, not appreciably affected by that of a particular individual. In considering whether to buy a mobile phone, an individual only assess the benefits the phone will bring, given the range of marketable goods available. She does not take into account that, if most people have mobile phones and the (full, inclusive of convenience) costs of communication are lower, this may trigger an increase in the range of marketable goods available. This increase depends on the general availability of phones, not on whether she herself has one. Thus, the general possession of phones that reduces communication costs (part of transaction costs) is a public good that may help to increase the level of division of labour. It is this second public-good aspect that this paper is emphasising, not the possibly public-good nature of the infrastructure investment itself.

In terms of (8), the individual benefits of an improvement in transaction efficiency is the increase in utility as either $k$ increases or $c$ decreases. The social benefits include the individual benefits plus the increase in utility from a higher $n$ induced by the increase in $k$ or the reduction in $c$ or both. Consider first an increase in $k$ only, the individual benefit is, from (8),

$$\frac{\partial u}{\partial k} \bigg|_{n} = (n - 1) \left\{ \frac{[1 - c(n - 1)]}{m} \right\}^{an} n^{(a-1)n} k^{n-2}$$

If we treat $n$ as a continuous variable, the social benefit of an increase in transaction efficiency $k$ is given by

$$\frac{\partial u}{\partial k} = (\frac{\partial u}{\partial k}) \bigg|_{n} + (\frac{\partial u}{\partial n})(\frac{\partial n}{\partial k})$$

If we start from a position where individuals have already adjusted to the given level of $k$ in their choice of $n$ (making $\frac{\partial u}{\partial n}$ approximately zero) and for a marginal change in $k$, the application of the envelope theorem implies that the social benefit is equal to
the individual benefit (with of course appropriate summation over the relevant set of
individuals where publicness is involved). However, developments in infrastructure is
typically lumpy and changes in n can only take on integer values. For such changes,
social and individual benefits may diverge significantly. Note that lumpiness as such is
insufficient to give rise to the divergence. If there is no publicness in the network of
specialization, the individual will take account of the indirect benefit of a higher k
through n, i.e. \((\partial u/\partial n)(\partial n/dk)\) in the right hand side of (10) in evaluating the benefits of
a higher k. Thus, it is the combination of lumpiness and publicness that causes the
divergence between individual and social benefits. Since n can only assume integer
values, strictly speaking we cannot really use (10) which may however be taken as
indicative of the various effects involved. We shall use illustrative examples involving
numerical values for the variables involved. For example, if we take \(m = 50, a = 1.215, k = 0.9, c = 0.0092\), it can be calculated that the integer value of n that maximizes the
utility value as given in (8) is 44, yielding a value (in units of \(10^{-104}\)) 12.093. An
improvement in transaction efficiency in the form of a reduction of c to 0.009, with all
other parameter s held unchanged, increases the utility value to 28.529 at unchanged
value of n. However, with the value of n adjusted to the lower c (n* increases from 44
to 47), the utility value increases further to 30.134. So the social benefits of the
reduction in c exceeds the individual benefits by 30.134 - 28.529 = 1.605 units. The
divergence of social and individual benefits associated with an increase in k may be
similarly illustrated.

The analysis above examines the willingness to pay for improvements in
transaction efficiency without explicitly modelling the financing or resource
implication of the investment to improve the transaction efficiency. To do this in a
simple example, suppose that a private firm can produce a device that improves the
transaction efficiency by reducing c (or increasing k). The device can be sold to all
individuals in exchange for a certain amount of their labour time \(l^d\) (d for device)
which can be used to produce the device. Thus, we assume that there is no public-good
free-riding problem for the device. The model above may be revised to account for this by replacing (3) with

\[(3') \quad c(n-1) + l^d + l_i + \sum_{j\neq i} l_j = 1\]

and with \(c\) (or \(k\)) dependent on whether \(l^d\) is incurred or not. Correspondingly, (8) is replaced by

\[(8') \quad u = \left[ \frac{1 - c(n - 1) - l^d}{m} \right]^{\frac{m}{(a-1)m}} n^{m} k^{n-1}\]

Let us start with \(m = 50, a = 1.215, k = 0.9, c = 0.0092, l^d = 0, n = 44,\) and (in units of \(10^{-10^4}\)) \(u = 12.093.\) Now, suppose that a lumpy investment costing a per capita labour time of \(l^d = 0.018\) would increase the transaction efficiency \(k\) to 0.93927. Even if there is no public good problem in getting everyone to pay the 0.018, the improvement may not be feasible. Evaluated at the existing level of division of labour with \(n = 44,\) the higher transaction efficiency does not justify the required cost. With the values of other parameters unchanged but with \(l^d = 0.018, k = 0.93927,\) and \(n = 44,\) it can be calculated from (8') that \(u = 12.089466,\) lower than the original value of 12.093. However, if the lumpy investment is undertaken, the lower value of \(k\) will increase the optimal level of specialization. If the value of \(n\) is increased to its new optimal value of 45, the value of \(u\) increases to 12.18331, making the investment well worth undertaking.

The argument above may be illustrated partially in Figure 1. The curve \(U_0\) relates the utility level at different values of \(n\) at the original parametric values. Ignoring the relevant costs, an improvement in transaction efficiency may lift the curve to \(U_1.\) At the original level of specialization represented by \(n^*_0,\) the gain is \(AB.\) If this gain is less than the costs, the net-of-cost curve \(U_2\) passes below \(A.\) However, there is an additional gain as the level of specialization increases to \(n^*_1,\) possibly making the new optimal point \(E\) higher than the original point \(A.\) However, evaluating the
improvement at the original level of specialization, the private market may not sanction the improvement even if there is no difficulty in overcoming the first public-good problem of getting everyone to pay for the change.

3. Concluding Remarks

Our analysis above is mainly illustrative. The simple functional forms assumed are mainly for simplicity and analytical manageability. They may under or over-estimate the situations in the real world. Thus, the quantitative values have no particular real-world significance. For the latter, we have to undertake specific quantitative estimates of the real economies, which is beyond the scope of this paper and the competence of its authors. Nevertheless, our analysis does provide a possible ground for the encouragement in lumpy improvements in transaction efficiency, including the provision of infrastructure. More specific policy implications may be obtained after further developments and applications to ascertain the actual situation and estimate the relevant values.

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Chu (1997) and Wen (1997) also use the Yang-Ng framework to analyze the role of infrastructure in economic growth. However, they concentrate on the positive aspects (such as the role of population density and the time path of growth) without discussing the possible rationale for encouragement.
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