Positive Externalities and the Public Provision of Transportation Infrastructure: An Evolutionary Perspective

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ABSTRACT

Do transportation systems, comprising infrastructure, service, and use, produce external benefits? If they do, should positive externalities be accounted for in the evaluation of infrastructure investments? This paper argues that while direct, technological, external benefits from transportation are difficult to find, meaningful positive externalities can arise from transportation systems in at least two ways. First, transportation infrastructure can reduce preexisting negative externalities, and the reduction of external cost must be considered an external benefit. Second, because transportation is essentially a derived demand its effects are broadly diffused throughout the primary markets that induce transportation demand. To the extent that changes in transportation infrastructure induce positive externalities in these primary markets, external benefits should be attributed to transportation.

A ONE-SIDED EXTERNALITIES DEBATE?

The general discussion on externalities of transportation—be they monetary or technological—usually concentrates on negative effects. In this paper, we concentrate on positive effects, although

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most scholars would question their existence—and in most cases they are right if the external effect is defined purely on a technological basis, leaving out monetary effects.

Consequently, most of the approaches used to evaluate the effects of externalities relate to the difficulty of pricing negative technological external effects.[1] We may distinguish between:

- The *resource approach*. The value of the externality is defined by the corresponding resource price of the private market, which in most cases relates to prices for damage or repair.
- The *avoidance approach*. The value of the externality is defined by the possibility of substituting the resource, the technology, or the good in question for a resource, technology, or good without the external properties.
- The *risk approach*. The value of the externality is defined by the discounted expected monetary value based on an evaluation of risk.
- The *utility approach*. The value of the externality is defined by the willingness to pay in order to reduce negative effects.

The scientific argument behind this apparent one-sidedness—which only accounts for negative effects—is that the positive effects of transportation investments are immediately captured by markets, unless market failure impedes it, whereas most negative effects remain external. This view is reflected in most of the literature.[2] Policy measures not correcting for this asymmetry must necessarily lead to allocation failures.

The most intuitive examples of negative externalities might be the adverse effects of infrastructure, for example, dividing up a landscape or vehicle emissions. It is very difficult to imagine external benefits (e.g., the beauty of a bridge in the case of infrastructure) or something comparable to "positive emissions." The very abstract concept of mental maps derived from a high degree of mobility and facilitating extended interaction spaces might be useful, though very unlikely.

The question is: what is ground zero? To what sort of alternative do we compare the existing transportation system? If we know the reference point, all effects "below" may be referred to as negative externalities, all effects "above" as positive externalities. Of course we know that this objective reference point does not exist, and there is no chance to objectively derive it. Thus, reductions in negative externalities may be considered as net positive externalities.

A more challenging issue seems to be that transportation demand is derived from other markets. If external effects exist in these "primary markets," they are in a causal sense transferred from one place to another. This link is not restricted to geographical locations; it may also refer to other metrics, that is, product space. The capacity of these links may be an important factor in the transfer of externalities. At the limit, without the transfer no market would exist and, thus, no externality issue.

In this paper, we investigate the external benefits of transportation stemming from spatial transfers from one primary market to another or from supply to demand. From what is known about spatial analysis (Blum 1996), it is clear that once markets or points of production and consumption are linked by means of interaction (i.e., transportation in geographical markets, substitutive exchange in product markets), the derived transportation demand (or transfer) function reflects excess demand and supply as well as underlying externalities. Furthermore, the effect will depend on the degree of perfection of these markets, that is, the more they are monopolized, the smaller the transfer effect.

Let us look at some intriguing examples:

- A vaccine prevents the spread of a disease once a sufficient proportion (below 100%) of a population has been vaccinated. Thus, all those who are not vaccinated benefit from an external benefit. If such a vaccine is shipped into a new market, external benefits emerge there, and their

[1] The willingness to pay for reduced noise normally differs from costs for technological improvements in cars or actual costs incurred in the medical sector.

[2] The analysis of negative externalities of transportation in Germany reveals costs that vary between 44 bn DM and 221 bn DM p.a. (IWD 1996). Growth effects are mostly analyzed within the framework of production models (Blum 1982). External benefits have been reported in Germany by Aberle (1992, 1994), who especially stressed the spatial aspects, the aspects of market integration, and cost savings; however, it has been argued that these benefits are not external at all as they are included in the allocation via the price system.

level will depend on demand that, again, will be partly influenced by transportation costs—which makes the institutional setting of the transportation market of crucial importance.

- Knowledge produced in one region is transferred to another region by means of commerce: the level of external benefits in the sense of spontaneous adjustments to the economy will depend on the intensity of this transfer, and it will be difficult to capture these effects from the beginning because of the existence of non-knowledge or uncertainty (Knight 1921). Market integration, however, triggered by the same transport system may produce sufficient information to grasp the issue and internalize it.
- The existence of a transportation system allows production and consumption nodes to interact, enabling them to produce economies of scale and of scope, and network economies. According to the new growth theory, they are external to the firm and can only be captured once sufficient information is available.
- Visitors to a resort island benefit from the beauty of nature, depending on the number of people allowed on the island.

All these external benefits are surpluses in the transportation demand system; in the price-volume diagram, a social transportation demand function with a higher reservation price reflects the level of demand if all positive externalities were properly accounted for by the individuals.

The structure of the rest of this paper is as follows: the next part classifies goods according to demand and supply characteristics; then, a model is proposed to link the characteristics of goods to varying congestion levels, a dominant characteristic of the use of infrastructure. Finally, we show that this classification provides new insights into the way infrastructure allocation is organized and costs and benefits are evaluated.

INFRASTRUCTURE, PUBLIC GOODS, AND EXTERNALITIES

Public Goods

Following the classic definition by Samuelson (1954, 387), goods are public "which all enjoy in common in the sense that each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good." As a consequence, consumers cannot be *excluded* from consumption and there exists no *rivalry* for consumption.

In this definition, the *pure public goods* are one pole of a continuum that extends to *pure private goods* at the other end. It was quickly discovered, however, that ideal public goods rarely exist in reality and that private allocation is possible once mechanisms can be found that:

- prevent the free use of these public goods, and
- force groups to reveal their preferences, at transaction costs that do not reduce demand to zero.

Symmetrically, pure private goods are also only an ideal counterpart to the ideal public good; the spectrum between these poles may be seen as a continuum that we will address later. This leaves unresolved the question of what type of good a road really is, for instance. In fact, it is easy to find roads or other types of infrastructure that can be positioned at different points on this continuum. The following observations may serve as a first challenge to the easy categorization of infrastructure:

- there is no such thing as rivalry per se; it depends on congestion and thus may vary widely for the same infrastructure. Once a motorway is filled to capacity, the situation is different from when it was empty.
- exclusion depends on the relative weight of transaction costs that vary in space and time. Some of these transaction costs are "natural," while some are created in order to force the revelation of preferences.
- the quality of the public good may depend on location, that is, a constant quality and/or quantity is not guaranteed.[3]

In fact, we see that given a fixed infrastructure capacity, exclusion reduces congestion and therefore also rivalry.

Our main argument is as follows: the quality of a public good is not only a supply-side characteristic but also relates to demand (i.e., preferences). As

[3] Security is an example of the thinning out of a public good in a spatial setting (Blum and Dudley 1991).

a consequence, the usual one-dimensional classification of goods from pure public to pure private no longer applies. This interaction of supply and demand was implicitly mentioned by Buchanan (1965) when defining the optimal size of a club good.[4] In fact, the issue of optimal size of a club relates to the problem of how to measure in real terms what goods people want if the market principle is not completely applicable. The club good then is characterized by the ability to exclude consumers, but no rivalry in consumption exists. It is worth noting that:

- All club goods can be declared public goods if capacity is set above zero price demand. For transportation, this is often the case for a highway in a sparsely populated area.
- The same holds true for private goods, if the government floods the market with free goods (i.e., if mass transit is declared free, as is the case in some European cities).
- Club goods can be changed into private goods, that is, by selling individual seats instead of selling to groups in a charter flight.
- A true public good cannot be turned into a club or a private good. If it is not a true public good, however, then privatization is possible if control and exclusion costs become manageable, e.g., decoding units in the field of communications.

It becomes clear from the arguments given above that capacity and how it is used may be key to the proper categorization of goods.

Categories of Externalities

External effects are impacts of activities in one market on another market without compensation.[5] They affect the property rights of persons not participating in the latter market. A distinction can be made between *externalities of cost* that are, by definition, captured by a market, and *technological externalities* (Scitovski 1949/50), where the activity in one market affects the individual production or the individual utility function in another market without a transfer through the market mechanism. The transfer may be prevented because of missing institutional arrangements: in the case of external diseconomies, there is no automatic incentive to capture these effects; in the case of external economies, market imperfections may prevent inclusion in the price system.

Incentive Structure and Externalities

If positive external economies are produced by the existence of infrastructure, changes in land prices, for example, occur as consumer demand (use) increases. Even if the initial externalities have been internalized, there is no guarantee that all effects stemming from this change in demand (and thus congestion) are accounted for—be they positive or negative—by transaction costs.[6] Thus, institutional arrangements may play a decisive role. Positive external economies may be sufficiently strong to overcome the level of transaction costs that inhibits internalization directly, or that may trigger the formation of new institutional arrangements. However, what happens if these changes are not feasible because the institutional arrangement has been adapted? What happens—in the sense of the initial discussion—if the necessary volume of vaccines cannot be transported because the infrastructure capacity is inadequate or too expensive (or both), if information exchange is incomplete because the flow of goods is hindered, or if visitors cannot access the empty island?

Seemingly, the ability to transfer externalities depends on the institutional setting of the transportation system, or more concretely, on the organization of infrastructure. We propose two classifications[7]:

1. The basic question of supply is to what extent—given a certain technology—rivalry exists and exclusion is possible. In the case of no rivalry and no exclusion, a public good is a given. The combination of exclusion without rivalry defines the club good. Both rivalry and exclusion are conditions for private procurement.

[4] A club good is one where the members of the club enjoy a public good and others are excluded. Some argue that highways are a club good, since one needs a motor vehicle to be in the club that enjoys the good.

[5] See, for instance, Arrow (1970) and Cornes and Sandler (1993).

[6] The issue of transaction costs and their impact on externalities was recently discussed by Demsetz (1996), with a focus on possible internalization strategies of the public.

[7] For an example, see Blum and Mönius (1998).

2. The basic question of demand is what prices—given a certain capacity—are applicable or set, for example, by policymakers. For prices $q = 0$ we have a public good; for prices $q > 0$ we obtain a club or a private good.

The general structure is given in table 1; t_c are exclusion costs for club goods, t_p for private goods, $t_p > t_c$. It is evident that the actual exclusion prices for public goods are zero, as nobody is excluded; the hypothetical exclusion costs are extremely high. For example, if a single driver has random access to a public road system, under the institutional setting of a public good, his exclusion would be extremely costly to enforce—thus exclusion prices are zero and all drivers have free access. This dichotomy also holds for other types of goods: without a change of institutional setting, actual exclusion prices for a certain type of good are always higher than if the hypothetical exclusion mechanisms for another type of good had been chosen.

In table 1, rivalry and excludability characteristics of goods are matched with demand, where prices are given exogenously (e.g., set by politics). Examples are in parenthesis.

External Economies and Control Costs

If external economies and costs emerging from setup, exclusion, and rivalry, which we now call control costs, are characteristics of markets, two criteria permit us to classify the allocation of goods:

1. *Positive (external) economies,* that is, economies of scale, of scope, and network externalities imply that the yield increases more than proportionately with input. In many cases, these external economies are a direct consequence of market integration enabled by transportation or communications networks.
2. *Control* is the ability to monitor, exclude consumers, and manage a good; it depends on transaction costs and, thus, the institutional structure (Coase 1937; Williamson 1975) that influences internalization mechanisms.

With increasing use, congestion and thus rivalry may grow. It may be operationalized by the (positive) opportunity costs of supplying additional quantities to maintain the competition at the existing level. Furthermore, positive (external) economies may be reduced, thus lessening the "public" or "club" element in the good. Once total rivalry exists and results in the need to exclude additional consumers, either a pure club good or a private good emerges. Club goods are likely outcomes if joint consumption of the club can be maintained, otherwise a private good is likely.

Mobility facilitates the transfer of external benefits, which might otherwise go unrealized, from one place to another. Take, for instance, an underutilized mass transit system offered as a public good; users only pay marginal costs with fixed costs financed by general taxes. The externalities of one market can easily be transferred to another market. If a road with little congestion is privately

TABLE 1 Demand and Supply Categories of Markets

Demand/ Supply	$q = \mathbf{0}$	$q > \mathbf{0}; q - t_c > \mathbf{0} > q - t_p$	$q > \mathbf{0}; q - t_p > \mathbf{0}$
No exclusion, no rivalry	Public (neighborhood street) ↑	— (not offered)	— (not offered)
Exclusion, no rivalry	Public* (highway, toll possible) ↑	Club toll road ↑	Private* or club (opera seats in the same row)
Exclusion and rivalry	Public* (congested highway, toll possible) ↑	Club* (congested toll road) ↑	Private (chewing gum)

* Asterisks show inefficient allocations, and the arrows give the direction of efficient change.

offered and users have to pay fixed costs, the transfer between markets will become more expensive and externalities will no longer spill over with the same intensity.

Once demand increases, congestion can be prevented by charging user fees and organizing clubs, for example, through electronic road pricing. If congestion continues to increase and the exclusion of some potential consumers becomes too expensive (they might revolt), the system will collapse—any transport then would have to become private. However, if with more funds invested in the system the system would produce above proportional yields (i.e., equal to carrying capacity), then these additional transactions could be offset and the system could remain stable.

It is clear that if external economies exist, they might overcome additional costs. This leads us to a model that allows us to formally delimit the different goods' characteristics.

CATEGORIZATION OF GOODS

The Basic Model

What is the path from private to club and public goods? Is it possible to derive functions that discriminate between these three categories? The following model is based on the assumption that if more than one person demands the same public good, a spillover occurs because of the non-exclusion principle. Economic efficiency is achieved when the sum of all individuals' marginal rates of substitution curves between this public good and all other private goods and equals the marginal rates of transformation for the infrastructure in question.

Let us start with the maximization of a utility function for two goods, a private good x and a nonprivate good y—the latter of which may later turn out to be either a club or a public good:

$$\max{:}U(x,y). \tag{1}$$

This function is subject to a budget constraint:

$$q \cdot x + k \cdot y = B, \tag{2}$$

where q is the price of the private good, k is the control costs incurred by the household for the nonprivate good, and B is the budget. Let us assume that x satisfies the same needs as y, that is, x is the private substitute for a nonprivate y. Because of positive spillovers and with increased demand, unit costs fall:

$$k \rightarrow \frac{k}{\lambda}\ ,\ \lambda > 1, \tag{3}$$

where λ is an externality factor, for example, a participation index. Forming the Langrangian L and taking first derivatives, we obtain:

$$\frac{\partial L}{\partial x} = \frac{\partial U}{\partial x} + \mu \cdot q = 0, \tag{4}$$

$$\frac{\partial L}{\partial y} = \frac{\partial U}{\partial y} + \mu \cdot \frac{k}{\lambda} = 0, \tag{5}$$

$$\frac{\partial L}{\partial \mu} = q \cdot x + \frac{k}{\lambda} \cdot y - B = 0. \tag{6}$$

Nonprivate procurement would be preferred if:

$$\frac{\frac{\partial U}{\partial x}}{q} < \frac{\frac{\partial U}{\partial y}}{\frac{k}{\lambda}}. \tag{7}$$

If households are unable to distinguish between the utility stemming from x and y and if the good is either demanded totally or not at all because of indivisibility, we may derive for nonprivate procurement:

$$\lambda > \frac{k}{q}\ , \tag{8}$$

that is, positive external economies have to overcompensate for the relative costs of nonpublic allocation if they are to be beneficial. We may set $q = 1$ and simplify to:

$$\lambda > k. \tag{9}$$

Let us now assume that the system is more general. Following our description in the preceding part, three goods are available: a public good (y), a club good (z), and a private good (x). The respective costs or prices are k, p, and q. The system then becomes:

$$\max: U(x,y,z), \tag{10}$$

subject to

$$q \cdot x + k \cdot y + p \cdot z = B. \tag{11}$$

We start with an externality factor λ for the club good and an externality factor μ for the public good, $\mu > 1$. The choice for a public good becomes:

$$\frac{\frac{\partial U}{\partial z}}{\frac{p}{\lambda}} < \frac{\frac{\partial U}{\partial y}}{\frac{k}{\mu}}. \tag{12}$$

Again, we may simplify by assuming that households consider *y* and *z* to be identical. Then the system reduces to:

$$\lambda < \mu \cdot \frac{p}{k}. \tag{13}$$

If we further assume that the offer of the (smallest possible) club good has to match the price of the private good, we may set $p = q$, and as $q = 1$:

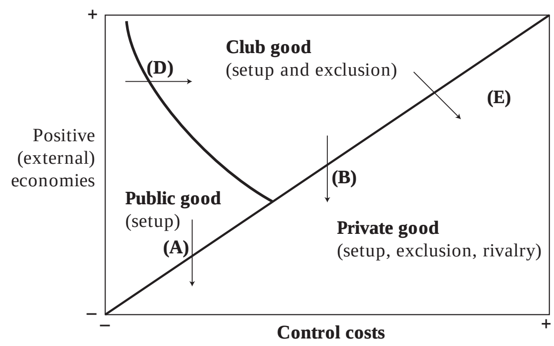
$$\lambda < \mu \cdot \frac{1}{k}. \tag{14}$$

The delimitation between club goods and public goods is thus a hyperbola: the more positive externalities public goods comprise, the larger their domain.

Organization of Goods and the Impact of Congestion

In figure 1, positive external economies and control (exclusion) costs are the two principal dimensions; the relationship is shown by a line from the lower left to the upper right corner. Above that line, the benefits supplying the good on a nonprivate basis exceed the unit costs of setup and exclusion under the institutional setting of a public or a club good. The lower triangle constitutes the region of private goods. Furthermore, the choice between public goods and club goods rests with the question of whether rising control costs can be offset by (external) benefits or not. If so, the public good is preferable, otherwise the club good becomes more advantageous. The delimitation is given by the hyperbola line from the upper left corner to the center. We see that:

FIGURE 1 The Two Dimensions of Goods Space



- If (external) benefits decrease, then goods previously provided as public or club goods may have to become private as they no longer can win back their setup costs (A) or their exclusion costs (B).
- If control costs for public goods increase, then the provision as club goods (D) and, ultimately, as private goods (E) becomes more likely in order to overcome the rising costs of the now inefficient institutional arrangement.

Generally, any shift in congestion would amount to changes in control costs, which makes the efficient goods provision—as already shown in table 1—a function of demand and capacity. Furthermore, increased levels of congestion would impede market integration and reduce economies of scale and scope, and network economies, thus limiting the yield of the existing arrangement. We may argue that the two externality indices, λ and μ, are decreasing functions of congestion and that control costs, *k*, increase with congestion, because of their relation to rivalry and exclusion. Whereas private provision needs an optimal degree of utilization, this may be difficult to control in a public or a club environment. Overutilization would then lead to private arrangements unless it can be compensated for by falling unit control costs or additional externalities.

The bottom line of this argument is that externality problems may be solved in cases of congestion by changing the institutional structure, that is, by privatizing slots for road use as well as by actions that maintain the public good character of transportation infrastructure (e.g., expanding capacity). This is compatible with Knight's (1924) proposition that the implementation of Pigou-taxes can be avoided if congestion allows privatization.[8] Furthermore, this internalization may produce sufficient profits to induce additional traffic, which may be one reason why induced traffic is so difficult to forecast (Blum 1998).

CONCLUSION

Positive technological external effects[9] can spill over from supply to demand or from one market to another once the infrastructure is offered efficiently, that is, according to the level of congestion that influences setup, exclusion, and rivalry costs, as well as the yield through economies of scale and scope, and network economies in the primary markets. In the case of a pure private procurement—when demand reaches levels where public or club provision becomes unsustainable—pricing may even capture some of the external benefits as it forces people to reveal (to a greater or lesser extent) preferences (e.g., make the participants in the market pay for the externalities stemming from vaccines, from knowledge transfer, or from the amenities of an uninhabited island).

If, however, congestion is low, the emergence of external benefits is only possible if transfer is not "too expensive," as forcing users to pay the full price of infrastructure would completely eliminate the very transfers that generate positive external benefits.

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[8] The author is indebted to an anonymous referee for this valuable information.

[9] The concept can easily be transferred to monetary external effects.