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PUBLIC GOODS, CLUB GOODS AND THE MEASUREMENT OF CROWDING

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Abstract

The paper shows that some frequently used measures of the degree of publicness of publicly provided goods and club goods are seriously affected by metrization problems. The paper proposes measures that do not depend on arbitrary metrization conventions, and discusses the relationship of these measures to the question of private provision and optimal club size.

Keywords: Publicness, crowding, quasi public goods, club goods
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The theoretical benchmark case of a pure public good has received wide attention in the public economics literature. Numerous empirical studies, however, have found that public services provided at the community level are subject to heavy crowding effects.[1] A central element of all these studies is a crowding function of the form

$$z = Z(g, n) \tag{1}$$

Here g denotes the quantity of a publicly provided good, and n is the number of users. g may be measured either in physical units or as expenditures. For the issues raised in this paper, the distinction is irrelevant. Furthermore, the two measures are equivalent under constant returns to scale in the production of the good. The variable z is to be understood as the usefulness of the provided good to the individual (Bergstrom and Goodman [1, p.282]) or the amount of the good captured by the individual (Borcherding and Deacon [2]). It is often called the "service level" derived from the provision of g. If g is a private good, $z = g/n$. Conversely, if g is a purely public good in the sense of Samuelson, $z = g$. More interesting and more problematic is the case of impure, also called rivalrous, public goods, where users cause *some* degree of congestion. Little thought has been spent on the exact meaning and measurement of z in this case, and the failure to do so has led to considerable confusion in the literature when results of studies are compared which implicitly use different methods to define z. Closely related to the measurement of z is the question of how to define the degree of publicness of g.

The contribution of this paper is twofold: first it presents three essentially different methods to define and measure z, and proposes measures of publicness of g that do not depend on the way in which z is measured. Equipped with a solid definition of publicness, it then discusses interesting characteristics of crowding functions and how these are related to the question of whether a good can be efficiently provided by private competing clubs. In particular, it investigates the role of the concept of increasing marginal congestion, which has attracted considerable attention in the literature.

[1] The seminal papers by Borcherding and Deacon [2] and Bergstrom and Goodman [1] triggered a huge literature; for a recent survey, cf. Reiter and Weichenrieder [10].

1 Metrization

This paper abstracts from excludability issues and concentrates on crowding effects. Therefore, we need not distinguish between impure public goods and club goods, which are defined as excludable impure public goods (Cornes and Sandler [4, p.347]). In addition, we assume that there is only one publicly provided good, g, and that private goods can be aggregated and measured in monetary units.

In this framework, the utility of household i can be written as

$$u^i = V^i\left(x^i, g, n\right) \tag{2}$$

where x^i is household i's consumption of the private good in money units. The literature does not work with the general formulation (2), but imposes (implicitly) the assumption that the marginal rate of substitution between g and n is independent of x^i, so that (2) can be decomposed into

$$u^i = U^i\left(x^i, z\right) \tag{3}$$

and the crowding function (1). We follow this tradition and make the assumptions necessary to justify representation (3).

One should note that (2) is not a "pure" utility function, but is conditional on the technology available in the public sector. For example, if g is the input of policemen, the utility of individuals depends on the technical ability of the police to produce safety. If z is some measure of safety, (1) can then be understood as a public sector production function. For a given state of technology, however, specification (2) is more general than the combination of (1) and (3), since it requires no separability assumptions.

The utility specification (3) and (1) leaves open the question of how z should be defined or measured. Only an ordering is imposed on z. The reason is that for any positive monotone transformation $\phi(.)$, the specification

$$u^i = U^i\left(x^i, \phi^{-1}(z)\right) \tag{3'}$$

$$z = \phi\left(Z\left(g, n\right)\right) \tag{1'}$$

is equivalent[2] to (3) and (1) and only amounts to a remetrization of z. The choice of a metric for z is a matter of convention, and in this sense arbitrary. It has nothing to do with the real economic structure, i.e., the observable behavior of households.

For most theoretical purposes, for example the characterization of Pareto-efficient allocations, an exact definition of z is unnecessary, because the introduction of z is a superfluous intermediate step. In empirical applications, however, where z is either measured or, if not really measured, at least interpreted, it is of crucial importance to be aware of the intrinsic metrization problems that are posed by the formulation (3) and (1).

There are at least three different metrizations that appear plausible:

1. A natural metric. If, for example, the good in question is highway services, we may choose z as the speed at which highway travel can flow (Inman [9]). One should note that a natural metric is not unique. For example, one might use the log of speed rather than speed itself.

2. Money metric. Here we define z as the willingness to pay for the use of the public good. If we assume that U is of the quasi-linear form

$$U = x + z = x + Z(g, n) \tag{4}$$

where the private good x is measured in currency units, money metric is unique. Otherwise, the willingness-to-pay will depend on the total income of a household, and we get different money metrics for different income levels.

3. The proportional metric. Given n, we take z as being proportional to g:

$$z = g \cdot \xi(n) \tag{5}$$

for some function $\xi(n)$, decreasing in n. Using the normalization

$$\xi(1) = 1 \tag{6}$$

[2]Quasi-concavity of U is also preserved. Requiring concavity of U would impose restrictions on the transformation ϕ.

the proportional metric is unique. It is important to note that (5) is not just a metrization, but plays the dual role of making a substantial assumption plus choosing a metric. The substantial assumption is that, for given n, the marginal rate of substitution $-Z_n/Z_g$ is proportional to g. Otherwise, a representation of the form (5) is not possible. But even if this assumption is met, a metric different from (5) could still be chosen. Metrization is a matter of convention.

For a simple illustration, assume

$$U^i\left(x^i, g, n\right) = x^i + g^{0.5}n^{-0.4} \tag{7}$$

Using the money metric, we get

$$z^{mm} = g^{0.5}n^{-0.4}, \qquad u^i = x^i + z^{mm} \tag{8}$$

With the proportional metric we get

$$z^{prop} = gn^{-0.8}, \qquad u^i = x^i + \sqrt{z^{prop}} \tag{9}$$

Generally, we cannot expect any two of the three metrizations to be equal (up to a multiplicative constant). Since money metric is equivalent to willingness to pay, and the proportional metric refers to physical quantities, the two can be proportional to each other only if the marginal willingness to pay for the physical quantity g is constant. This is clearly a very special and economically implausible case. A natural metric of z is expressed in units (speed, crime rates etc.) of a different category than either willingness to pay or the physical quantity of g (highway length, number of policemen etc.). There is therefore no presumption that a natural metric should be proportional to a money metric or a proportional metric. A simple example may clarify the point: doubling the length or width of a highway will normally not exactly double the speed of cars.

2 Measuring Publicness

Different metrizations have in fact been used in the literature. Most of the papers following Borcherding and Deacon [2] and Bergstrom and Goodman [1] use the proportional metric, with the special assumption

$$\xi(n) = n^{-\alpha}, \qquad \alpha > 0 \tag{10}$$

Brueckner [3] uses the reduction in expected fire losses (p.48), which is a form of money metric. Craig [5, fn.5] uses a natural metric: safety, measured as a constant minus the crime rate.[3] Edwards [7] states four properties that should be fulfilled by reasonable congestion functions. These requirements are fulfilled by (and are actually weaker than) the proportional metric. Edwards then investigates five different congestion functions, four of which use the proportional metric. He notes that the fifth one (Generalized Congestion Function, GCF) does not meet the four requirements. However, this function may well make sense if used together with a natural metric, as Inman [9] originally did.

The measure of publicness most widely used in the literature is the elasticity of z with respect to n, keeping g constant:

$$\eta_n^z = \left.\frac{\partial z}{\partial n}\right|_{g=\bar{g}} \cdot \frac{n}{z} \tag{11}$$

The discussion of the last section has made it clear that this is a problematic measure as it depends on the arbitrary metrization of z. Elasticities are invariant only to multiplicative changes of variables, but the different metrics we have discussed are not multiples of one another. This can be seen from the example of the last section: while equations (8) and (9) represent the same utility function, the elasticity η_n^z is -0.4 in the case of (8) and -0.8 in the case of (9). It is therefore misleading to compare elasticity estimates in studies that use different metrics, as is sometimes done in the literature. For example, Brueckner [3, p.53] uses a money metric and finds a congestion elasticity of -0.24, which is much lower than the values of about -1 usually found. Transforming Brueckner's congestion function (8) into a proportional metric, the congestion elasticity would be $\gamma/(\alpha+\beta) = -0.60$ (in Brueckner's notation). This still indicates considerably less crowding than is usually found, but not so dramatically less as Brueckner's interpretation suggests[4]. Craig [5,

[3] Note that even in this simple case, choosing different constants leads to different metrizations of z which are not proportional to one another.

[4] In his Footnote 15, Brueckner mentions the potential problem of measuring fire protection services, but seems not to recognize the nature of the metrization problem.

p.346f.] uses a natural metric and compares his congestion elasticity to those found in the studies using a proportional metric (similar in Craig and Heikkila [6]). Edwards [7] compares the results of the GCF function, which uses none of the above three metrics, to results of four different functional functions, all of which use the proportional metric.

It would obviously be very useful to have a definition of publicness that does not depend on the metrization of z. This can indeed be achieved by measuring the increase in the quantity of the public good which is necessary to keep consumers' utility constant when population increases. The relevant elasticity is

$$\eta_n^g = \left.\frac{\partial g}{\partial n}\right|_{z=\bar{z}} \cdot \frac{n}{g} \tag{12}$$

Since z is kept constant, the elasticity η_n^g is independent of how z is measured and reflects only the shape of the indifference curves in (g, n)-space.

The definitions based on (11) and (12) are equivalent only in the case of a proportional metric, since $\eta_n^g = -\frac{N\xi'(N)}{\xi(N)} = -\eta_n^z$. If applied in conjunction with a metric other than the proportional one, definitions based on η_n^z are inappropriate, a fact that seems not to be recognized in the literature. For example, Brueckner [3, p.47] uses a money metric and defines a private good as a good where $\eta_n^z = -1$. We argue that one should rather define a private good by the condition $\eta_n^g = 1$. The first advantage of this definition is that it is independent of the metrization of z, as argued above. In addition, we will show in Section 3 that it has the property that an excludable good is private if it can be efficiently provided by competitive private clubs. This is generally not true for the definition based on η_n^z.

We will discuss the relationship between measures of publicness and the efficient provision of goods more systematically in Section 3. First, however, we provide a comprehensive list of definitions, following the insight that measures of publicness should be independent of z.

Definitions of publicness

1. A good is purely public if

$$u(x, g, n) = u(x, g, 1), \qquad \forall\, g, n, x \tag{13}$$

2. A good is purely private if

$$u(x, g, n) = u(x, g/n, 1), \qquad \forall\, g, n, x \tag{14}$$

For the impure cases, we distinguish between average and marginal publicness. The average concept refers to the comparison between the situation where n individuals consume g units of the public good, and the situation where one individual consumes g/n units. This leads to the following definitions.

3. At point (g, n), a good is *averagely*

$$\begin{cases} \text{overcongested} & \text{if } u(x, g, n) < u(x, g/n, 1) \\ \text{private} & \text{if } u(x, g, n) = u(x, g/n, 1) \\ \text{impure public} & \text{if } u(x, g/n, 1) < u(x, g, n) < u(x, g, 1) \\ \text{public} & \text{if } u(x, g, n) = u(x, g, 1) \\ \text{camaraderie} & \text{if } u(x, g, n) > u(x, g, 1) \end{cases} \tag{15}$$

The marginal concept is concerned with local changes in n and g and therefore makes use of the elasticity η_n^g.

4. At point (g, n), a good is *marginally*

$$\begin{cases} \text{overcongested} & \text{if } \eta_n^g > 1 \\ \text{private} & \text{if } \eta_n^g = 1 \\ \text{impure public} & \text{if } 0 < \eta_n^g < 1 \\ \text{public} & \text{if } \eta_n^g = 0 \\ \text{camaraderie} & \text{if } \eta_n^g < 0 \end{cases} \tag{16}$$

Note that a purely public (private) good is also averagely and marginally public (private).

Next we define quantitative measures of average and marginal publicness. They are normalized to have the value 1 for public and 0 for private goods. The publicness measures can be understood as 1 minus a congestion measure. *Marginal publicness* at point (g, n) is naturally measured by

$$MP(g, n) = 1 - \eta_n^g \tag{17}$$

There are certainly several possible definitions of *average publicness* at point (g, n). We propose the formulation

$$AP(g, n) = 1 - \left(1 - \frac{G(1; g, n)}{g}\right) \cdot \frac{n}{n-1}, \qquad n > 1 \tag{18}$$

where $G(n'; g, n)$ is the level of g necessary to achieve the same utility level as at (g, n) with n' users, formally

$$U\left(x^i, G(n'; g, n), n'\right) = U\left(x^i, g, n\right) \tag{19}$$

Definition (18) has the required property that, for a pure public good, $AP = 1$ because $G(1; g, n) = g$, while for a purely private good $AP = 0$ because $G(1; g, n) = g/n$. Of course, the proposed measures are invariant with respect to transformations of the utility function (2).

If we adopt a proportional metric, we can easily express the above publicness concepts in terms of g and z. This is trivial for the marginal concepts because $\eta_n^g = -\eta_n^z$. The average publicness measure (18) is given by

$$AP = \frac{n}{n-1} \cdot \frac{z}{g} - \frac{1}{n-1} \tag{20}$$

This is similar to Edward's (1990, equation 3.1) measure $z/g - 1/n$. Both measures assume the value 0 for purely private goods. For purely public goods, our measure is exactly 1, contrary to Edward's, which is bounded from above by 1.

3 Important Properties of Crowding Functions

In this section we discuss several properties of crowding functions that have figured prominently in the literature. We are mainly interested in whether these properties are independent of the metrization of z, and how these properties relate to the economic question of public or private provision of goods. In the following, we assume that the public good g is perfectly divisible. Edwards [8] analyzes the interesting case where g is not perfectly divisible. Indivisibility does not change the logic of the metrization arguments presented above, but it makes the decision whether public or private provision is desirable more complicated.

Iso-elasticity

As mentioned above, most of the literature uses the proportional metric (5) with the specification (10). This gives

$$\eta_n^g = \alpha \tag{21}$$

For $\alpha = 1$, we have a purely private good. Club or city size is then irrelevant. For $\alpha > 1$, the optimal club size would be infinitesimally small, for $\alpha < 1$, the optimal club size would be infinite.

U-shape

Goods for which publicness varies with population size and quantity of the good provided are more interesting. Then there is often an optimal finite club size for given z^* (or utility level $U(x, g^*, n^*)$). This is the case if the average cost function (assume g is measured as expenditures)

$$AC(n) = \frac{G(n; g^*, n^*)}{n} \tag{22}$$

has an interior minimum, or more specifically, is U-shaped. The minimum is at a point where[5]

$$\eta_n^g = 1 \quad \text{and} \quad \left.\frac{\partial \eta_n^g}{\partial \ln n}\right|_{z=Z(g^*,n^*)} > 0 \tag{23}$$

[5] To see this most easily, note that minimizing (22) w.r.t. n is equivalent to minimizing $(\ln g - \ln n)$ for given z w.r.t. $\ln n$. The first order condition then is $\frac{\partial \ln g}{\partial \ln n} - 1 = \eta_n^g - 1 = 0$, and the second order condition is $\frac{\partial^2 \ln g}{\partial (\ln n)^2} = \frac{\partial \eta_n^g}{\partial \ln n} > 0$.

Once this size has been sufficiently exceeded, more people are best served by replicating clubs, and the good is private in this sense. Note that the optimal club size, and more generally the question of whether the good can be efficiently supplied by private clubs, can be determined by measures that are independent of any metric of z. This provides a justification of the publicness measures proposed in Section 2. Other measures of publicness are appropriate only if they are compatible with those. For example, Edwards [8, p.566ff.] provides conditions for U-shaped average costs which use a measure similar to η_n^z, but they are equivalent to ours since his analysis is in the framework of a proportional metric.

Increasing marginal congestion

A property of crowding functions that has received attention in the literature is *increasing (absolute) marginal congestion* IMC, defined as

$$\frac{\partial^2 Z(g,n)}{\partial n^2} < 0 \tag{24}$$

Craig [5, p.338f.] and Edwards [7, p.84] indicate that IMC is a more natural assumption than decreasing marginal congestion. Note that this property again depends crucially on the metrization of z. Most studies discuss IMC in combination with the proportional metric (in which case it simply means $\xi'' < 0$). The literature seems to have overlooked that IMC together with the proportional metric has implications that are extremely implausible from an economic point of view. Assume there is a n^0 such that $\xi'(n^0) < 0$ (this simply means that the good is not a camaraderie good for all n). IMC implies, for a given g, that the service level $z = 0$ is reached at a finite population level n^* where

$$n^* < n^0 - \frac{\xi(n^0)}{\xi'(n^0)} \tag{25}$$

$z = 0$ is the service level which is reached if $g = 0$, i.e., if the good is not provided at all. This situation is called "gridlock". If $z = 0$ for $n = n^*$, however, the proportional metric obviously implies that z is zero for *all* values of g. In other words, gridlock occurs at n^* no matter how much of g is provided! Given the near inconsistency of IMC and proportional metric, it is comforting that Edwards [7] is able to reject IMC. Craig [5] finds IMC in an empirical application using a natural metric, where it may well make sense.

4 Summary

In the last three decades, great efforts have been made to measure the publicness of publicly provided goods. The results provide potentially important information for privatization decisions. This paper has argued that some of the measures used to characterize publicness are flawed since they depend on arbitrary metrizations. The paper has described measures that are not affected by this problem, and has briefly discussed how they relate to the question of private provision and optimal club size. Finally, the paper argued that increasing marginal congestion is not an essential characteristic of a local public good or a club good.

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