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HEC Montréal

April 2009

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April 25, 2009

*We wish to thank Stefan Ambec, Olivier Bochet, Vincent Boucher, Bettina Klaus, Sidartha Gordon, Dipjyoti Majumdar, Hervé Moulin, Yves Sprumont, Nicolas Sahuguet, Bernard Sinclair-Desgagné and William Thomson, as well as participants of the Montréal Natural Ressources and Environmental Economics Workshop and FQRSC for financial support.

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Abstract: The siting of public facilities, such as prisons, airports or incinerators for hazardous waste typically faces social rejection by local populations (the "NIMBY" syndrome, for Not In My BackYard). These public goods exhibit a private bad aspect which creates an asymmetry: all involved communities benefit from their existence, but only one (the host community) bears the local negative externality. We view the siting problem as a cost sharing issue and provide an axiomatic foundation for Lindahl pricing in this context. The set of axioms we introduce are specifically designed to overcome the asymmetry of the problem.

Keywords: Public goods; Externalities; NIMBY; Location; Cost sharing.

JEL Classification Numbers: D61, D62, H41, Q53, Q58, R52, R53.

1 Introduction

The siting of public facilities, such as prisons, airports or nuclear waste disposals typically faces social rejection by local populations. These goods are socially necessary but come with local externalities (noise, pollution, noxious odors...) or bear a negative connotation. Different factors can be the cause of such rejection: the loss in the economic value of property, the perceived loss in quality of life or the fear of health effects. In economic terms, these public goods have a private bad aspect to them which creates a siting problem: all communities benefit from the public good, but only one—the host—bears the local nuisance. This asymmetry typically leads to costly procedures or inefficient siting[1]. Worse, for some difficult cases no host has yet been selected (e.g. a nuclear waste disposal in the United States, see the Environmental Protection Agency, 2002). Such cases can even result in a stalemate.

The literature coins this public rejection phenomenon the *NIMBY* syndrome, for Not In My BackYard. In practice, conventional approaches to the siting of a "local bad" are currently characterized by a decide-announce-defend structure (see the Environmental Protection Agency, 2002, and Marchetti, 2005, for comprehensive reviews). First, (secret) investigations are carried out by the governing institution to evaluate the technical suitability of a location. Then, the prospective host community is confronted with the siting proposal and promises of compensation. In fact, without compensation it seems difficult for the host to accept a noxious facility.

In practice, a difficulty one faces when implementing such a project is that the planner typically has access to much less information than the involved parties, which causes a revelation problem. The mechanism design literature tackles the problem by designing procedures procedure which are *decision-efficient*: the chosen host should be the one which incurs the lowest hosting cost (consisting of the cost of construction and a disutility component) among all communities[2].

[1] See Minehart and Neeman (2002) or Marchetti (2005).

[2] See Kunreuther and Kleindorfer (1986), Sullivan (1992), O'Sullivan (1993), Minehart and Nee-

However, another aspect of the siting problem relates to the sharing of the cost borne by the host community so as to guarantee the stability of the agreement. Taking into account such redistribution issues helps ease the siting process itself and reinforces the stability of the agreement. And if not carefully considered, the structure of the compensation itself could result in the rejection of the project, as pointed out in Easterling (1992) and Frey et al. (1996). Furthermore, reviewing four cases of waste disposal facilities in the Canadian context, Khun and Ballard (1998) conclude that inequity perception and political dimensions (beyond the economic implications) were the main causes of the NIMBY effect. Similarly, Pol et al. (2006), adopting a social-psychological approach, review previous literature and point out that *"the outcomes and lines of argument [reviewed] present the NIMBY issue in terms of distributive justice, inequity perception and risk attribution."*

The traditional approach in the economic literature focuses on the strategic properties of the procedures without treating explicitly the redistribution issue. By contrast, in a companion paper (Laurent-Lucchetti and Leroux, 2009) we design a simple mechanism to select an efficient site which preserves incentives and allows the implementation of any reasonable redistribution scheme. Knowing that such a mechanism exists begs careful examination of the siting problem from a redistributive viewpoint.

Therefore, we shall ignore here any issue of strategic revelation and assume that cost and benefits parameters are known. Through the use of axioms specific to the NIMBY context, we characterize a cost sharing method which shares the hosting cost so as to ease the redistributive issues tied to the siting problem. It turns out that the set of properties we define precisely characterize Lindahl pricing, which coincides in this context with proportional sharing of costs with respect to benefits. Traditionally, numerous issues of public financing are settled using Lindahl prices. However, despite its well-known appealing properties in the standard case of public good provision, the relevance of Lindahl pricing in the specific context at hand (combination of a public

man (2002) and Perez-Castrillo and Wettstein.

good and a private bad) had not yet been ascertained as it was not *a priori* obvious that sharing costs solely according to benefits could be desirable.

The relevant characteristics we consider to model the problem consist of two components: the benefit a community obtains from the existence of the public good (b_i for community i) and the hosting cost of each community, c_i, interpreted as the construction cost plus a disutility if it is selected to host of the facility. Up to now, studies on the siting issue have focused on the cost parameter to dictate the redistribution. We believe that adding a benefit component enhances the model in at least two ways. First, it determines explicitly whether the public good should be constructed or not (if the sum of the benefits exceeds the total cost). Second, and most importantly, it justifies a bound on the cost share each community will be asked to pay. Thus, ignoring the benefit component would amount to ignoring the voluntary participation of each community, which could be very problematic for the stability of any solution. In fact, benefits are traditionally central to the allocation of costs in public good contexts.

We focus on the notion of *responsibility* to define axioms of interest: communities should pay solely for aspects for which they are responsible and be compensated for aspects for which they are not. We introduce two natural properties designed to level the playing field between the participants. Indeed, because all communities share the same responsibilities towards the public good *ex ante* (before the host is selected) the host should not bear any more responsibility *ex post* (after it is selected). In this regard, the first property we define mitigates the fact that efficiency requires the host to be initially treated asymmetrically due to the fact that its hosting cost alone determines the total cost. We propose to adapt a standard solidarity requirement of the classical cost-sharing literature: *cost monotonicity* requires that if the total cost were to increase, no one should pay less than before. Transposed unaltered to the NIMBY context, cost monotonicity would imply that if the host's cost were to increases, no community should have to pay a lower cost share. In order to recover symmetry, we extend this responsibility to *all* communities and require that cost monotonicity apply to all (potential) hosting costs. We call this property *extended cost monotonicity*: if the hosting cost of *any* community were to increase no community should pay less than before. In addition, as argued in Laurent-Lucchetti and Leroux (2009), *extended cost monotonicity* also has an appealing strategic implication as it guarantees that the proposed mechanism is immune to coalitional deviations.

The second property we ask of a sharing rule is related to our interpretation of the characteristics of a community as the aggregation of its inhabitants'. Thus, the benefit-cost profile is subject to change as a result of population movements. In practice, population movements are often observed after the announcement of a host and may thus be endogenous (a point raised by Sullivan (1990) and Baumol and Oates (1998)). Some agents (living in a non-host community) with very low disutility for the proximity of the facility may move near the facility because of lower housing prices or because of other advantages brought by the compensation scheme (e.g. improved public infrastructures), while agents with high disutility may choose to move out of the host community. This, in turn, may affect the communities' characteristics and their resulting cost share. To ensure *ex post* equity we address this issue explicitly and define the following property: if population movements occur between a subset of communities, they should collectively pay the same cost share as a result and communities outside of this subset should be unaffected. In other words, communities are held responsible for their own characteristics but not for the distribution of the cost-benefit profile. We call this property *Migration Independence.*

In addition to these properties, which are specific to the siting issue, we also require efficiency and voluntary participation. We show that Lindahl pricing, which coincides in this context with proportional sharing with respect to benefits, is the unique efficient method which meets Extended Cost Monotonicity, Migration Independence and Voluntary Participation.

2 Related Literature

The financing of public goods in the NIMBY context has been widely studied in economics by considering the siting of a private bad. Typically, each community is identified by a hosting cost (c_i), then an auction-like procedure elicits a site (the community with the lowest hosting cost, for efficiency) and a compensation scheme is constructed to ensure incentive compatibility.

The first paper to study the problem of siting waste treatment facilities in this way is Kunreuther and Kleindorfer (1986). They propose a sealed-bid auction procedure to create an incentive for each community to truthfully reveal their costs (disutility plus technical cost of hosting the facility): each community pays its own bid. O'Sullivan (1993), Minehart and Neeman (2002), Perez-Castrillo and Wettstein (2002) also propose auction mechanisms in the same vein, aiming for efficiency and truthful revelation. The traditional trade-off between efficiency, incentive compatibility and budget balance is central in these papers and they tackle the siting issue exclusively from a strategic viewpoint. However, they are silent with regards to redistribution.

By contrast, in a companion paper (Laurent-Lucchetti and Leroux, 2009) we design a simple mechanism to choose an efficient site which allows the implementation of any reasonable redistribution scheme. The unique subgame-perfect Nash equilibrium of our mechanism coincides with truthtelling, is efficient, budget-balanced and is immune to coalitional deviations. Thus, it selects an efficient host and shares the cost in a predetermined way so as to achieve virtually any normative goal (such as the solution we propose here).

Taking a normative approach, Marchetti and Serra (2004) consider the siting problem as a cooperative game. They study the standard solutions of cooperative game theory (the Shapley value, the nucleolus and the core) with an asymmetric value function: the value of the cooperation changes when the host changes. They design an experiment and test which solution is the most appealing to participants. However, our modeling is quite distinct from theirs, as we wish to explicitly disentangle the public good aspect (the benefit component) and the private bad aspect (the hosting cost) of the siting problem.

Sakaï (2006) axiomatizes the properties of the proportional procedure used by Minehart and Neeman (2002). However, the model he uses is different from ours: he considers a waste disposal facility where the benefits that each community obtains from the facility are equal to the amount of waste generated by this community. By contrast, we consider a broader set-up where the benefits that each community obtains from the public good could be independent of the "intensity" of consumption of the good; for instance, a community could obtain a high benefit from the existence of a prison without sending any of its inhabitants in it.

3 The model and axioms

Let $N = \{1, ..., n\}$ be the set of communities. Each community $i = 1, ...n$ obtains a benefit, $b_i \geq 0$, from the consumption of the public good and incurs a cost, $c_i \geq 0$, if it is the host of the public good. We view the characteristics of a community as the sum of those of its inhabitants. Let $(b, c) = (b_i, c_i)_{i \epsilon N}$ be the benefit-cost profile. For any agent $i \in N$, (b'_i, b_{-i}) refers to the vector b where b_i has been replaced by b'_i,a nd for any subset $S \subseteq N$, b_S denotes the projection of b onto $\mathbb{R}^S_+$. We consider the cost parameter to be a combination of the physical construction cost and the disutility each community endures if it is the host of the public good.

Without loss of generality we rank communities from lowest to highest cost: $c_1 \leq c_2 \leq .... \leq c_n$. Efficient siting requires that the host be a lowest cost community: thus, we consider community 1 to be the host. Moreover, we assume $\sum_N b_i \geq c_1$ so that it is always efficient to build the facility. Hence, an efficient cost-sharing method assigns a vector of nonnegative cost-shares $x(b, c) \in \mathbb{R}^N_+$ such that $\sum_N x_i(b, c) = c_1$.

To overcome the natural asymmetry of the problem (one community bearing the cost for the benefits of all) we define a number of properties for the cost-sharing method which aim at leveling responsibilities among communities. The first properties are standard fare in the distributive justice literature. We then introduce two additional properties specific to the siting problem.

A basic incentives property is that of voluntary participation: communities should not pay more than the benefits they obtain from the existence of the public good:

Voluntary Participation (VP): For all $b, c \in \mathbb{R}_+^N$ and all $i \in N$, $x_i(b, c) \leq b_i$.

The second property reflects our view that communities are responsible for their own characteristics. It states that if a community is in a profile in which it obtains higher benefits from the existence of the public good, all else equal, then it should not have to pay a lower cost share:

Monotonicity in benefits (b-MON): For all $b, b', c \in \mathbb{R}_+^N$ and all $i \in N$,

$$b_i \leq b'_i \Rightarrow x_i((b'_i, b_{-i}), c) \geq x_i(b, c).$$

The same argument holds for the hosting cost: a standard requirement, called cost monotonicity, states that no community should pay less if the total cost (the cost to the host in our framework) were to increase. Because we wish the solution to not treat the host asymmetrically, *Extended Cost Monotonicity* extends the responsibility of the host community to the collective: it holds each community equally responsible for the total cost and subjects all communities to cost monotonicity:

Extended Cost Monotonicity (ECM): For all i,$j \in N$,

$$c_i \geq c'_i \Rightarrow x_j(b, (c'_i, c_{-i})) \geq x_j(b, c)$$

A possible justification of ECM is the following: because *ex ante* —when the identity of the host is still unknown—the decision to build a facility is a collective one, and because the cost parameter alone determines the identity of the host, the sharing rule should treat the cost parameter of all communities somewhat symmetrically (including that of non-host communities). In other words, the host is not any more responsible for the total cost just because its own cost happens to be the lowest in the distribution. The sharing rule should reflect this fact. In addition, as argued in Laurent-Lucchetti and Leroux (2009), ECM also has an appealing strategic implication as it guarantees that the equilibrium of the proposed mechanism is immune to coalitional deviations.

Finally, our last property reinforces our argument according to which no community is responsible for the distribution of characteristics: if population movements occur between a subset of communities, they should collectively pay the same joint cost share and communities outside of this subset should be unaffected:

Migration Independence (MI): For all b,$b', c, c' \in \mathbb{R}_+^N$ and any $S \subseteq N$:

$$\left.\begin{array}{rr} & \sum_{j\epsilon S} c'_j = \sum_{j\epsilon S} c_j \\ \text{and} & \sum_{j\epsilon S} b'_j = \sum_{j\epsilon S} b_j \\ \text{and} & min_{i\in S}(c_i) = min_{i\in S}(c'_i) \end{array}\right\} \Longrightarrow \left\{\begin{array}{rr} & x_i((b'_S, b_{-S}),(c'_S, c_{-S})) = x_i(b,c), \forall i\epsilon N\backslash S \\ \text{and} & \sum_{j\epsilon S} x_j((b'_S, b_{-S}),(c'_S, c_{-S})) = \sum_{j\epsilon S} x_j(b,c) \end{array}\right. .$$

This property directly addresses the concern of endogenous migration linked to the NIMBY problem raised by the applied literature (see Sullivan (1990) and Baumol and Oates (1998)): some agents may move near the facility or away from it after the announcement of the project. *Migration Independence* insures that the cost shares of communities are unaffected as much as possible after those migrations. This property is related to the well-known axiom of No Advantageous Reallocation (NAR) in claims problems, like the rationing and surplus sharing contexts. NAR is used in particular to characterize the egalitarian rule, the proportional rule, as well as many other surplus-sharing methods (see Moulin, 2002). NAR addresses the problem of strategic manipulation of claims and asks that no agents gain by reallocating their claims among themselves. However, the normative content conveyed by our formulation is far from strategic, as we consider migration decisions to be out of the communities' control.

4 Lindahl Pricing

In our context, Lindahl prices can be defined as follows for any i:

$$x_i(b,c) = \frac{b_i}{\sum_N b_j} c_1 \tag{1}$$

This method simply shares the cost proportionally to the benefits each community obtains from the public good. In other words, it shares the hosting cost by applying a "flat rate", $\frac{c_1}{\sum_N b_j}$, to each unit of benefit that a community obtains from the existence of the public facility. Given that the provision of the public good is binary, pricing according to marginal benefits is tantamount to charging according to benefits.

Theorem: Given n $\geq$ 3, Lindahl pricing is the unique efficient cost-sharing method meeting *VP*, *ECM*, and *MI*.

Proof: See Appendix.

The intuition for why this method meets *MI* is that if population movements occur between a subset of communities their aggregate cost share remains constant because the sum of benefits remains. This method meets *VP* because the ratio $\frac{c_1}{\sum_N b_j}$ is less than one by efficiency. Clearly, *ECM* is satisfied.

Other intuitive ways of splitting the hosting cost exist. For instance, the constrained egalitarian method (where the total cost is equally split among communities, up to the voluntary participation constraint) fails to satisfies *MI*. Indeed, when population movement occurs, it is possible for certain communities to benefit from a change in the population distribution while other communities suffer: a movement from an unconstrained community which "transfers" a higher benefits to a constrained community, everything else equal, will lead to an increase in their aggregate cost share and other communities will benefit. Also, sharing the hosting cost in proportion to each community hosting cost (the $c_i^\prime s$) obviously fails *ECM*: a higher hosting cost (for a community other than the host) means it will pay a higher cost share, thus benefitting all other communities.

5 Conclusion

We have characterized a simple solution to finance a public good in the NIMBY context. Our aim was to capture the specificity of the problem (one community bears the cost, benefits accrue to all) and overcome it by an appropriate method which focuses on redistributive properties: the host should no longer be perceived as a "victim". Thus, we designed a set of axioms which level the playing field among communities by arguing that communities are responsible for their own characteristics but not for the distribution of the benefit-cost profile. It turns out that this set of axioms characterizes Lindahl prices, which coincide here with the proportional sharing of cost with respect to benefits.

In practice, the planner interested in implementing Lindahl prices must obtain information on (b, c), the benefit-cost profile. In fact, in a companion paper (Laurent-Lucchetti and Leroux, 2009), we propose a procedure which elicits the benefit-cost profile and selects an efficient host while implementing any redistribution scheme.

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A Proof of Theorem

Let x be an efficient cost-sharing method which meets *VP*, *ECM* and *MI*.

Step 1: Consider a benefit-cost profile$(b, c) \in \mathbb{R}_+^{2N}$. Let $c' \in \mathbb{R}_+^N$ be such that $c'_1 = c'_2 = ... = c'_n = c_1$. By *ECM* no agent should pay a higher cost share under profile (b, c') than under profile (b, c): $x_i(b, c) \geq x_i(b, c')$ for all $i \in N$. By budget balance the cost shares in profiles (b, c) and (b, c') should coincide:

$$x(b, c) = x(b, c'). \tag{2}$$

Hence, the cost shares of each agent are solely determined by the profile b and the lowest cost c_1. From now on we will slightly abuse notation and write $x(b, c_1)$ instead of $x(b, c)$.

Step 2: We now show that, by *MI*, the cost share of an agent i is determined by b_i, $\sum_{j \neq i} b_j$ and c_1.Let $i \in N$ and let $b, b' \in \mathbb{R}_+^N$ be such that $b'_i = b_i$ and $\sum_{N \setminus i} b'_j = \sum_{N \setminus i} b_j$. By *MI*, agent i should obtain the same cost share under profiles (b, c) and (b', c): $x_i(b', c_1) = x_i(b, c_1)$. So, $x_i(b, c_1)$ depends only upon $b_i, \sum_{j \neq i} b_j$ and c_1 for all $i \in N$. It follows immediately that x_i depends only upon $b_i, \sum_{j \in N} b_j$ and c_1 for all $i \in N$. .

Step 3: Let $c_1 \in \mathbb{R}_+$, $i, j \in N$ and $b, b' \in \mathbb{R}_+^N$ be such that $b'_i = b_i + b_j$, $b'_j = 0$ and $b'_k = b_k \ \forall \ k \neq i, j$. For notational convenience, we define $B = \sum_{j \in N} b_j = \sum_{j \in N} b'_j$ By MI, $x_i(b'_i, B, c_1) + x_j(b'_j, B, c_1) = x_i(b_i, B, c_1) + x_j(b_j, B, c_1)$. By *VP*, $x_j(b'_j, b'_N, c_1) = 0$. Thus,

$$x_i(b_i + b_j, b_N, c_1) = x_i(b_i, b_N, c_1) + x_j(b_j, b_N, c_1). \tag{3}$$

Given c_1 and b_N, the cost share of community i is only determined by b_i. Again, we slightly abuse notations and rewrite equation (3):

$$x_i(b_i + b_j) = x_i(b_i) + x_j(b_j). \tag{4}$$

which holds for all b_i, b_j such that $b_i, b_j \geq 0$ and $b_i + b_j \leq b_N$.

Similarly,

$$x_j((b_i + b_j)) = x_i(b_i) + x_j(b_j). \tag{5}$$

holds for all b_i, b_j such that $b_i, b_j \geq 0$ and $b_i + b_j \leq b_N$.
Thus,

$$x_j \equiv x_i \text{ on } (0, b_N) \ \forall \ i, j. \tag{6}$$

By combining equations (3), (4), (5) and (6) we obtain:

$$x_i((b_i + b_j)) = x_i(b_i) + x_i(b_j). \tag{7}$$

for all b_i, b_j such that $b_i, b_j \geq 0$ and $b_i + b_j \leq b_N$, which is a Cauchy functional equation.

Step 5: Following a well-known result of functional equations theory (see Aczèl, 1966), the general solution of such a functional equation is a linear function. Thus,

$$x(b_i) = \lambda b_i \tag{8}$$

for all b_i in our domain.

Step 6: To conclude the proof we show that $\lambda = \frac{c_1}{b_N}$, a result which follows immediately from combining expression (8) with the budget-balance condition. Therefore,

$$x_i(b, c) = b_i \frac{c_1}{b_N} \tag{9}$$

which is precisely Lindahl pricing.