INTERNALISATION OF TRANSPORT NOISE EXTERNALITIES; ACTIVITY DISTURBANCE PRICING AND IMPLEMENTATION

Ernestine M. A. Gross
Macquarie Graduate School of Management

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Abstract

A transport noise pricing model is presented, which uses concepts and methods from general equilibrium theory concerned with non-dictatorial resource allocation systems. Transport noise is characterised as a negative externality; a map from the space of (non-marketable) transport sound commodities into an individual’s set of feasible actions (marketable and non-marketable human activities) such that the set of feasible actions is reduced. Conditions are provided under which the cost (welfare loss) to an individual of a transport noise event can be measured either in terms of real resource costs (duration of activity disturbances) or in monetary terms. The solution to the model allows the application of relatively simple (one-dimensional) mechanisms to address the problem of strategic behaviour when collecting data and it is consistent with single noise event methods.

Keywords
internalisation of transport noise externalities, duration of activity disturbances, incentive compatible mechanisms, incomplete markets, single noise event method
1. INTRODUCTION

Transport noise (and other community noise) has become an important problem for individuals, urban planners, governments, and transport service providers (WHO, 1993; Lambert and Vallet, 1994; Gross, 1994; Berglund and Lindvall, 1995, Report by the Senate Select Committee on Aircraft Noise in Sydney, 1995; Lambert et al, 1998; Schwela, 1998 among others). There is a problem of conflicting interests and this problem is expected to increase in the future: Demand for transport services is projected to increase but residents in many urban environments would like a reduction in noise pollution. Failure to address this problem entails misallocation of resources, either in the sense of some individuals gaining while others lose in terms of their personal welfare, or in the sense that the aggregate welfare losses due to transport noise outweigh the welfare gains from the provision of transport services. There is no ‘market solution’ to this problem of conflicting interests because there is no ‘market’ for transport sound. The institutional invention of tradeable pollution rights does not solve this problem; a non-market agent is required to determine the total amount of pollution, including an accepted methodology for measurement and costing of pollution levels. The need for economic methods to estimate the cost of transport noise for the purpose of project evaluation and the efficient ‘internalisation’ of these costs by means of polluter pays policies, is recognised (eg OECD/ECMT, 1994). It has also been recognised by the scientific community, concerned with the physiological effects of noise, particularly long term adverse health effects (ICBEN, 1998). To be useful for private and public sector decision makers, who employ financial methods as decision making aids, the economic cost estimates need to be expressed in monetary terms.

There are two existing economic methods of estimating a monetary value (cost) of transport noise, namely hedonic pricing and contingent valuation. This paper contains a transport noise pricing model, which uses the same welfare criterion as that used in the existing methods. However, in contrast to existing models, which use traditional microeconomic concepts and methods, this model is developed using concepts and methods from general equilibrium theory concerned with non-dictatorial resource
allocation systems. Moreover, it differs from the existing models in terms of the assumption regarding the role of market prices in allocating resources.

The model, known as hedonic pricing, makes a strong assumption about the structure of markets and hence the role of markets in allocating resources efficiently. It assumes that asset market prices (real estate markets) completely span the state space of decision variables.\(^1\) Hence real estate market prices are assumed to ‘fully reflect all relevant information’\(^2\) (‘revealed preference approach’) and the aim is to impute the cost of transport noise from real estate market prices. (Walter, 1975; Pearce, 1978; Nelson, 1980; O’Byrne et al 1985; Pennington et al, 1990; Uyeno et al 1993, Levesque, 1994; Renew, 1998 among others).

The alternative economic method, known as contingent valuation, makes an equally strong assumption about the role of markets in allocating resources, however at the opposite extreme. This method essentially assumes that market prices contain ‘no relevant information’. Consequently, attempts are made to estimate the ‘social cost’ of noise by trying to elicit information about individuals’ preferences directly (‘stated preference approach’) within the context of simulated choice situations (Soguel, 1996; Weinberger, 1992).

Hedonic pricing, developed in the specialist area of transport economics (Walter, 1975), is the most widely used and accepted economic method. However, its applicability is restricted to those cases where the ‘complete spanning’ assumption sufficiently closely approximates the actual conditions. Empirical researchers do not seem to appreciate the importance of the spanning condition (Starret, 1988; see also Kanemoto, 1988). For example, the aircraft noise sharing policy, introduced in Sydney and elsewhere, is not consistent with the complete spanning condition; in the limit there is not even one house, the price of which can reflect the absence of ‘noise’. Similarly, if residential location per

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\(^1\) In the specialist area of finance, the Capital Asset Pricing model makes an equivalent spanning assumption regarding financial assets (eg Jarrow, 1988)

\(^2\) This term is borrowed from the finance literature.
se is an element in the utility function of an individual (historical value, proximity to friends or place of work) then the spanning condition is violated, too.

Contingent valuation originated in the specialist area of environment and resource economics (Davis, 1963; Mitchell and Carson, 1989; Flatley and Bennett, 1996 among others). This method is considered to be controversial and costly (Arrow et al, 1993, Lambert et al, 1998). However, if a local environmental problem is 'big', in the sense that its solution would significantly disturb all local market prices, then these prices cannot be presumed to contain any relevant information and the contingent valuation approach seems to be difficult to avoid.

The model presented in this paper assumes that market prices do contain relevant information but ‘not all of it’, ie the market structure is incomplete and spanning does not hold in asset markets. The solution to the model reflects the incomplete market assumption because non-price information is required (‘duration of activity disturbances’) together with price information (personal income). In this model transport noise is characterised as a negative externality; a map from the space of transport sound commodities (non-marketable) into an individual’s set of feasible choices of marketable and non-marketable labour service commodities (human activities). The term ‘duration of activity disturbance’ is a straightforward interpretation of the precise characterisation of a transport noise externality. Only one additional assumption is required, relative to 'standard' assumptions in models of competitive economies, to obtain the solution of the model. This assumption is that each individual can sell only one type of labour service on any one day. Even though this assumption is not literally true - some teachers may work as waiters at night to supplement their incomes - it is considered to be a sufficiently close approximation to actual labour markets, at least in terms of income brackets.

The model offers an approach, which caters for empirical cases where the actual conditions neither approximate those assumed in the hedonic pricing model nor those assumed in the contingent valuation method. Furthermore, the model is useful to deal with project or location specific cost internalisation problems because single noise event
data can be related to activity disturbance costs to individuals, using small samples. To the extent that it is ethical to interpret long term adverse health effects of transport noise as extreme cases of activity disturbances (loss of income or reduced income over time or loss of enjoyment of leisure activities), the theoretical model in this paper provides a coherent economic framework for the integration of scientific data on health effects.

To avoid cumbersome notation, the transport noise pricing model in section 2 is presented in minimalist form. The problem of strategic behaviour in the collection of non-market data, which is severe in the contingent valuation method, also arises in the application of the present model. Individuals may have an incentive to misrepresent their preferences in terms of the duration of activity disturbances or personal incomes in order to, say increase compensation payments. This problem is addressed in section 3. It is shown that in contrast to contingent valuation, the solution to the present model allows the application of relatively simple incentive compatible mechanisms to induce 'truthful revelation' of preferences. Extensions of the model, including alternative assumptions about the institutional environment for the purpose of policy formation, are discussed in section 4.

2. TRANSPORT NOISE PRICING MODEL

Theoretical models of non-dictatorial resource allocation systems take as axiomatically given that each individual knows what is 'best' for him or her in terms of consumption of commodities. This idea is made precise by the concept of preferences (a preordering). A commodity is defined in terms of its physical properties, date of availability, location of availability. (Taking into account one notion of uncertainty, a state dependent commodity is defined as a commodity, which is made available conditional on a ‘state of nature’ occurring.) The interpretation of a ‘location’ in terms of geographical dimensions and the interpretation of a ‘date’ in terms of calendar time depend on the practical problem at hand. Quantities of a commodity are measured in appropriate units, eg. grams, miles, \{amplitude, phase\}. Transport sound satisfies the definition of a commodity.

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3 Debreu (1959)
Let \( I = \{1, \Lambda, I\} \) denote the set of individuals in an urban community. As an approximation, all commodities are assumed to be measurable in real numbers. Let \( x'_j \in \mathbb{R} \) denote the quantity of commodity \( j \); \( x'_j > 0 \) if commodity \( j \) is consumed by individual \( i \), \( x'_j < 0 \) if \( j \) is supplied by \( i \) and \( x'_j = 0 \) if neither consumed nor supplied. Let \( x_M \in \mathbb{R}^M_+ \) denote an \( M \)-dimensional vector of marketable consumption commodities (including transport services) and let \( p_M > 0 \) denote a strictly positive vector of prices for these commodities. Let \( x_L \in \mathbb{R}^L_+ \) denote an \( L \)-dimensional vector of marketable labour services with prices (wages) \( p_L > 0 \), and let \( x'_I \in \mathbb{R}^I_+ \) denote a vector of services, which are supplied by \( i \) for \( i \)'s own consumption. Examples of such services include gardening, watching TV, going shopping, and similar ‘leisure activities’. As a first approximation, sleep may also be considered as a ‘leisure activity’. These ‘leisure activities’ are non-marketable commodities and therefore there are no market prices. Marketable and non-marketable labour services may be referred to as ‘human activities’. Let \( y_N \in \mathbb{R}^N_+ \) denote a vector of transport noise commodities and let \( y = (y_L, y_M, y_N) \in \mathbb{R}^L_+ \times \mathbb{R}^M_+ \times \mathbb{R}^N_+ \) denote a production vector (project); input commodities are non-positive quantities and output commodities are non-negative quantities. To save on notation, \( M, L, I, \) and \( N \) denote respectively the set of marketable non-labour, marketable labour, non-marketable labour ('leisure') activities, and noise commodities as well as the (finite) number of commodities in each of these groups. The representation of transport noise by a finite dimensional Euclidean space is an approximation with the following interpretation. To allow for different human reactions to noise levels, as measured by say \( L_{(\text{max})} \) between ‘night’ and ‘day’ time, two ‘noise commodities’ are required for each day. Allowing for longer time periods or finer partitions of the time unit ‘day’, say hours, as well as other noise measures, say \( L_{(\text{eq}, x \text{ hrs})} \), \( L_{(\text{eq}, y \text{ hrs})} \) etc, the number of noise commodities, \( N \), may be very large\(^4\). Noise commodities are non-marketable.

\(^4\)Similarly, noise events, which differ regarding their frequency components, but not in terms of noise level, would constitute different commodities.
Each individual is assumed to have convex and closed preferences. Hence, preferences can be represented by smooth real valued utility functions\(^5\), \(u^i : \mathbb{R}^M_+ \times \mathbb{R}^L_+ \times \mathbb{R}^L_- \rightarrow \mathbb{R} \ \forall i \in I\). Let \(u_{ik}^i(x^i)\) denote the \(i^{th}\) individual’s marginal rate of substitution (trade-off) for the commodities \(k\) and \(z\) at a point \(x^i = (x^i_M, x^i_L, x^i_L) \in \mathbb{R}^M_+ \times \mathbb{R}^L_+ \times \mathbb{R}^L_-\). Each individual is assumed to be non-satiated in the consumption of marketable commodities and 'leisure' activities. To save on notation, asset markets are ignored\(^6\) and individual endowments are assumed to consist of marketable labour services and non-marketable ‘leisure activities’.

A transport service production is characterised by a production vector, \(y = (y_L, y_M, y_N) \in \mathbb{R}^L_+ \times \mathbb{R}^M_+ \times \mathbb{R}^N_+\). Transport sound occurs if \(y_h > 0\) for some \(h \in N\). Assuming individuals are ‘price takers in utility’, a decentralised solution to the problem of transport noise is provided by a Lindahl equilibrium\(^7\). In this case an efficient internalisation of the pollution costs means that the polluting transport service provider pays for the cost \(c = \sum_{i \in I} \sum_{h \in N} p_{ih}^i y_h\) where \(p_{ih}^i = u_{ik}^i(x^i, y_h) < 0\) is the \(i^{th}\) individual’s personalised relative price of noise commodity \(h\) in terms of a numeraire commodity \(r\). Each individual’s transfer (‘compensation’) is \(c^i = \sum_{h \in N} p_{ih}^i y_h\). If the polluter pays policy is not imposed, then the \(i^{th}\) individual carries a personal cost (‘noise tax’?) equal to \(c^i\) and the financial (commercial) value of project \(y\) over-estimates the economic value by an amount equal to \(c\).\(^8\)

The assumption of ‘price taking in utility’ implies ethical behaviour, which is often considered to be at variance with observed behaviour and it is incompatible with the assumption of ‘non-satiation’. Individuals may have an incentive to misrepresent their

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\(^5\) Debreu (1954)

\(^6\) The model could be extended to include asset markets, using either a temporary equilibrium approach (Grandmont, 1985) or a ‘rational expectations equilibrium’ approach in the sense of Radner (1972).

\(^7\) Lindahl (1967). For applications to environmental problems see Blad and Keiding (1990)

\(^8\) An example of the confusion between economic and financial value of an airport project and its consequences is described in Gross (1994).
preferences to, say increase their transfer payments. The application of non-cooperative game theory to design a 'mechanism' to induce individuals to 'truthfully reveal' their preferences will be discussed in section 3. At present, the aim is to simplify the problem by finding conditions such that the pricing of transport noise commodities does not require information on individuals' marginal rates of substitution between 'transport noise' and a numeraire commodity.

The elementary time period chosen is a day, denoted by t. This interpretation of a ‘date’ seems appropriate in terms of physiological characteristics of humans. It is assumed that the market structure is sequential (eg Radner, 1972, Kreps and Wilson, 1982) and that on any day each individual can sell only one type of labour service commodity in the market. On each day, each individual decides how to allocate his or her real resources (‘time’) between selling labour services for the purpose of ‘making money’ to buy ‘goods and services’ and leisure activities. The set of feasible choices of the ith individual is real resource constrained; the sum of the absolute values of the quantities of marketable and non-marketable labour services supplied on any one day, t, is equal to 1. Let \( \bar{X}^i = \{(x^i_{L_t}, x^i_{N_t}) \in \mathbb{R}^L_+ \times \mathbb{R}^N_+ : \sum_{j \in I_t} x^i_{jt} / \sum_{j \in I_t} x^i_{jt} = 1 \ \forall t = 1 , \Lambda , T \} \), with \( \mathbb{R}_-^L = \mathbb{R}_+^L \times \Lambda \times \mathbb{R}_+^M \) (identical embedding for \( \mathbb{R}_+^N \)), denote i's real resource constrained choice set (ie the set of feasible choices). Furthermore, each day, t, each individual i faces a budget constraint in the market for goods and services, namely \( p_M^i x^i_{M_t} + p_L^i x^i_{L_t} = 0 \ \forall t \). The assumption of ‘non-satiation’ yields equality of income earned and income spent in the market. It is noted that the budget constraint depends on the choice variable \( x^i_{L_t} \). To save space, only one day will be considered in the following and the subscript t will be dropped.

Without transport noise, ie. \( y_h = 0 \ \forall \ h \in N \), individual i decides on an allocation, which is ‘best’ in the sense of being most preferred by i (‘utility maximising’)

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9 As with asset markets, long term labour contracts could be incorporated by introducing more notation but without changing the basic structure of the model.
and the chosen allocation is budget and real resource feasible. Let \( \hat{x}^i = (\hat{x}_M^i, \hat{x}_L^i, \hat{x}_z^i) \) denote \( i^{th} \) choice with \( (\hat{x}_L^i, \hat{x}_z^i) \in \bar{X}^i \) and \( p_M \hat{x}_M^i + p_L \hat{x}_L^i = 0 \).

It is assumed that each individual can only sell one type of labour service on any one day, \( t \). Let \( L_i \) denote the marketable labour service, which \( i \) can make available at \( t \) and define all marginal rates of substitution for individual \( i \) with respect to \( L_i \). (The marketable commodity \( L_i \) provides a personalised numeraire commodity.) Individual \( i \)'s preference maximising choice is characterised by: (i) The equality of the marginal rates of substitution (personalised prices) of the ‘leisure activities’ and the personalised numeraire commodity, ie \( p_{L_i,k}(\hat{x}_L^i) = p_{L_i,z}(\hat{x}_L^i) \) all \( k, z \in I, k \neq z \); (ii) The equality of the marginal rates of substitution and the prices of consumption goods and services relative to the personalised numeraire commodity, ie \( p_{L_i,m} = p_{L_i} / p_m \) all \( m \in M \).

The opportunity cost (market value foregone) of non-marketable human activities can be deduced from \( i \)'s real resource constraint on human activities. It suffices to consider two non-marketable human activities, \( k \) and \( z \). The real resource constraint is \( \hat{x}_k^i + \hat{x}_z^i + \hat{x}_L^i = 1 \). The money income from selling an amount \( \hat{x}_L^i \) of the marketable labour commodity \( L_i \) is \( p_{L_i}(-\hat{x}_L^i) \). The feasible choice of non-marketable human activities, \( \bar{x}_k^i , \bar{x}_z^i > 0 \), implies that individual \( i \) values these activities at least as highly as the purchase of marketable commodities, which could be achieved by using the time to ‘make money’, ie \( p_{L_i,k} \hat{x}_k^i + p_{L_i,z} \hat{x}_z^i \geq p_{L_i} (1/ \hat{x}_L^i) = p_{L_i} \hat{x}_k^i + p_{L_i} \hat{x}_z^i \). Individual \( i \)'s optimal choice is illustrated in Figure 1 for the case of one consumption good, \( m \), one non-marketable labour service, \( s \), and the marketable labour service, \( L_i \). The points marked \( -\bar{x}_k^i , \bar{x}_z^i \) indicate the real resource constraint. The relative market prices, \( p_{L_i} / p_m \), imply a trade-off relationship between \( m \) and \( s \), ie the implied opportunity cost.
Figure 1.

The production of transport services creates a negative externality if for at least one individual in the urban environment the set of feasible acts is reduced.\textsuperscript{10} Examples of transport noise reducing the set of feasible acts for individuals are widely reported; sleep disturbances, reduced power of concentration, interference with viewing of television, listening to music, and conversations are some examples of activity disturbances, which were found to be associated with noise in psycho-acoustic studies (eg. Hede and Bullen, 1982, Gross and Sim, 1997, among many other). However, while psycho-acoustic studies examine the relationship between scale variables on 'annoyance' and 'activity disturbance' the duration of activity disturbances has not been measured\textsuperscript{11}.

Within the context of the present model, the production of transport services $y = (y_L, y_M, y_N) \in \mathbb{R}^L \times \mathbb{R}^M \times \mathbb{R}^N$ creates negative external effects if there exist a set of

\textsuperscript{10} The above definition of a negative externality is a straightforward application of the notion of an ‘externality’ as found in mathematical economics. For example in Blad and Keiding (1990, pp 253-4): “The fundamental common feature of all types of externalities is that the acts of one agent affects the set of feasible acts of other agents. The result may either be that the other agents obtain a larger set of possible choices - in this case we speak of a positive external effect - or they experience a reduction in their possibilities of choice, a negative external effect”.

\textsuperscript{11} Gross and Sim (1998) carried out a pilot study on the duration of activity disturbances.
maps, \( f_z^i : \mathbb{R}^N \rightarrow \bar{X}_i \), \( z \in L_i \cup I_i \) all \( i \in I \), such that for some \( i \in I \) the resulting set of possible choices \( \tilde{X}_i \) is ‘smaller’ than \( X_i \), ie. \( \tilde{X}_i \subset X_i \) strict. Noise pollution output \( y_h \), which disturbs activity \( z \) of the \( i^{th} \) individual by an amount \( x'_z(y_h) \) constitutes a reduction of possible choices, ie a negative externality. The amount \( x'_z(y_h) \) is measured in time (fraction of a 24 hour day). Hence, for a given choice, \( \hat{x}^i \), the real resource cost of a transport noise externality to individual \( i \) is measured in terms of the duration of activity disturbances. The implied market value of the external effect \( x'_z(y_h) \) is equal to \( p_{L_i} x'_z(y_h) \). (It is noted that the labour market price \( p_{L_i} \) relates to one unit, ie labour of type \( L \), which is supplied for 24 hours). The notation \( x'_z(y_h;i;\hat{x}^i) \) will be used to denote the duration of the disturbance of activity \( z \), given the optimally chosen vector or planned activities, \( \hat{x}^i \).

An external effect is illustrated in Figure 2; \( \tilde{y}_h \) has the effect of reducing the endowment of the real resource \( L_i \) from \( \bar{X}_L^i \) to \( \tilde{X}_L^i \).

![Diagram](image-url)
The externality function $f^i_z$ depends on the individual and on the type of human activity supplied at the time of the noise event, i.e., individual A may be more ‘noise sensitive’ than individual B with respect to all activities and A or B may be more ‘noise sensitive’ with respect to activity $k$ than $z$. However, the implied market value of the duration of disturbances is equal for all types of activities.

Like hedonic pricing and contingent valuation, this model assumes that external effects of transport services are separable, e.g., the effect of noise pollution does not interact with that of, say, air pollution. This is not a strong assumption for many human activities. However, compounding effects of various types of pollution on health violate this assumption.

3. IMPLEMENTATION

The internalisation of transport noise externalities requires that transport service producer $j$ with production vector (project) $y^j = (y^j_N, y^j_L) \in \mathbb{R}_{+}^M \times \mathbb{R}_{+}^L$ and noise events $y^j_N \in \mathbb{R}_{+}^N$ pays $c^j = \sum y^j_N p_L x^j (y^j_N; \hat{x}^j)$, where $x^j (y^j_N; \hat{x}^j) = \sum \sum x^j_i (y^j_N_i; \hat{x}^j_i)$, as defined in section 2 above, and individual $i$ receives a transfer payment $c^i = \sum y^j_N p_L x^j (y^j_N_i; \hat{x}^j_i)$ from transport service provider $j$. Given a set of technologically possible transport service projects $12$, $Y \in \mathbb{R}_{+}^M \times \mathbb{R}_{+}^L \times \mathbb{R}_{+}^N$, efficient resource allocation amounts to choosing that transport service technology, $y^* \in Y$, which yields the highest economic profit, i.e., $\tilde{p}y^* - c^y \geq \tilde{p}y - c^y$ all $y \in Y$. The first term in the definition of economic profit corresponds to the commercial or ‘market value’ of a transport service project. In an applied context, project $y'$ may differ from project $y$ in terms of the type of transport infrastructure (air, water, rail, road) or in terms of the utilisation of an infrastructure type (e.g., light aircraft versus heavy aircraft, time of the day).

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12 For the present purpose, it is sufficient to make only one assumption on the properties of the total production technology, namely that it is technologically possible to have no transport services, i.e., $0 \in Y$. 
of operation, flight paths modes, etc) or in terms of geographical locations, or in terms of construction methods (different road surfaces).

Trade-off decision problems between noise externalities and construction methods or operating modes amount to comparing the economic profits of alternative projects. Similarly, ‘abandonment decisions’ involve comparing the economic profits of existing versus alternative transport infrastructure or alternative utilisations. For some transport noise problems (eg aircraft, infrequent trucks, motor cycles), single noise events can be used to describe differences in transport service technologies.

While all variables in the internalisation solution to the model of section 2 are measurable, the empirical measurement of the duration of activity disturbances raises familiar methodological problems in research that involves human subjects. Laboratory studies offer control over at least some conditions. However, these methods may be intrusive, inducing behaviour changes. Alternatively, field studies, which rely on asking people to report the duration of activity disturbances (and state their personal incomes), are subject to the problem of strategic behaviour. In particular, non-satiated individuals have an incentive to overstate the duration and opportunity cost of activity disturbances in order to increase their wealth13. On the other hand, private owners or operators of transport infrastructure, whose objective it is to maximise shareholders’ monetary returns (ie commercial profits), have an incentive to minimise the transfer payments to noise affected residents by, say, understating the commercial profitability of alternative transport service productions. There is a conflict of interest problem and all agents have an incentive to misrepresent their private information. (In the present model private information refers to externality functions and associated opportunity costs in the labour market and transportation technologies and associated commercial profits.)

The objective of efficient internalisation of transport noise externalities, as described above, belongs to a class of planning problem (‘economic engineering’), which is addressed in the theory of implementation. The aim of this theory is to design game

13 Whether people are in fact as ‘greedy’ as assumed in general equilibrium models of competitive economies and in non-cooperative game theory is an unresolved empirical question.
forms (which in this literature are called ‘mechanisms’) such that the equilibria satisfy socially desirable properties but which do not require vast amounts of knowledge by the planning authority. Instead, the ‘rules of the game’ should be such that the social arrangements are self-policing. The designer should only make sure that the ‘rules of the game’ are respected by the ‘players’. This may entail enforcement of the rules by means of monetary or non-monetary fines. In the present context the problem consists of designing a game form which induces all ‘players’ (ie providers of transport services and residents, who are exposed to transport noise), to ‘truthfully’ state their characteristics (ie transport service technologies and associated commercial profits; externality functions and associated monetary opportunity costs in labour markets.)

The design of a mechanism requires the selection of a suitable solution concept, given the information structure of the game form. A social objective is said to be implementable with respect to the chosen solution concept. Since the pioneering work by Clarke (1971), Mirrlees (1971), Groves (1973), Groves and Ledyard (1977), implementation theory has developed rapidly, both in terms of basic research (eg necessary and sufficient conditions for implementation with respect to various solution concepts, the efficiency and dynamic properties of alternative mechanisms) and in specialist areas such as voting mechanisms, incentive compatible contracts, and the allocation of public goods.

The choice or development of a mechanism for implementing the solution of the model in section 2 depends on the particular applied problem. At present, it is useful to focus on the properties of the solution to the noise pricing model, which are useful for implementation in general. First, the dimensionality of the planner’s decision (the choice of $y^*$) can be reduced from $M+L+N$ to one (ie, $e \in \mathbb{R}$). The decision about the

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14 ie complete or incomplete information
16 eg Mookherjee and Reichelstein (1989), Laffont and Tirole (1987)
17 eg Cabrales (1999)
18 see Myerson (1991), Corchón (1996)
commercial part of transport service production, \( \tilde{y} \), can be decentralised, using market prices. However, this presupposes appropriate legislation to enforce payment of noise pollution costs. The one-dimensional planning problem is a desirable property of the solution to the model in section 2 because the set of existing mechanisms for one-dimensional planning problems is larger than the set of multi-dimensional planning decision problems.\(^{19}\) Hence the planner has more choice. Second, the solution to the model in section 2 fulfils the condition, provided by Mookherjee and Reichelstein (1989) for a class of models in which dominant-strategy implementation involves no welfare loss relative to Bayesian implementation.\(^{20}\) Mookherjee and Reichelstein assume that each individual \( i = 1, \Lambda , I \) has a quasi-linear utility function, \( u^i(x,k,\theta) = V^i(x',\theta') + k^i \), where \( \theta \) is a ‘state variable’ (eg agent type) and \( k^i \) is the transfer to agent \( i \). They allow \( x \) to be multi-dimensional, but require \( V^i \) to depend on \( x \) only through a one-dimensional statistic \( h^i(x) : u^i(x,k,\theta) = V^i(h^i(x'),\theta') + k^i \). The interpretation of Mookherjee and Reichelstein’s condition in terms of the transport noise pricing model of section 2 is straightforward. Let \( x = (x_M, x_L, x_I) \) be a \( M+L+I \) dimensional consumption, as defined in section 2. The state variable (agent type) for individual \( i \) is given by the externality map \( f^i \). For any real resource feasible choice \( \tilde{x}^i \in \tilde{X}^i \), there is an associated income function \( h^i(\tilde{x}^i) = p_L \tilde{x}_L^i \), which is a one-dimensional statistic. Finally, the solution of the model in section 2 is such that all agent types are an element in the closed interval \([0, \tilde{p}_L]\), where \( \tilde{p}_L \) is the maximum labour unit price. This feature of the solution allows the application of relatively simple mechanisms, which assume that the agent type space is one-dimensional.\(^{21}\)

4. DISCUSSION
Implementation theory may also be applied in conjunction with contingent valuation methods of estimating the monetary value (cost) of transport noise. However, the

\(^{19}\) At present, the literature on iteratively undominated strategy implementation and ‘virtual implementation’. Implementation considers only for one-dimensional decision problems.

\(^{20}\) See Fudenberg and Tirole (1996, 7.4.2).

proposed method, based on the duration of activity disturbances, has several advantageous features. Firstly, as outlined in section 3, the implementation problem is relatively simple and transparent. In particular, the fact that all agent types lie within a closed interval, given by 0 and the maximum 24 hour labour price, $\bar{p}_L$, means that any person with access to income statistics can form a plausibility judgement on the data. It is expected that this feature alone makes the proposed method less controversial than contingent valuation. Moreover, for many one-dimensional mechanisms, the minimum number of players is quite small (eg 3 in the case of Abreu and Matsushima's mechanisms). This implies that empirical methods, based on the present model are very flexible regarding location or project specific transport noise pricing problems. Second, the proposed method allows the separation of the noise pollution costs into real resource costs (duration of activity disturbance) and monetary costs, which is not the case either with contingent valuation or hedonic pricing. The advantage of this feature is that other than implicit labour market values may be applied. For example, the social norm of a particular society may be that the value of sleep should be positive and equal for all members, irrespective of individuals' ability to earn money in the labour markets. By collecting data on various types of activities, which are disturbed, it is possible to integrate social norms by means of administratively determined prices. Moreover, the method 'works' as long as all individuals (households) have positive income. Whether this is due to full employment or due to income redistribution policies is irrelevant. Furthermore, data on the duration of the disturbance of various types of human activities may provide more meaningful information to legislators than monetary aggregates.

22 Administered prices have been used to value positive externalities of transport. For example, 'travel time saved' is valued by means of administratively determined prices in the evaluation of road infrastructure projects in New South Wales, Australia (see the Road and Traffic Authority NSW Economic Manual, 1996) However, the theoretical justification for this method is obscure. The proposed method is a natural complement to the valuation of positive externalities, which would remove a possible bias in favour of road construction.
REFERENCES


