Sustainable Transportation Networks: Foundations: Part II

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Transportation and the Environment

Road pricing as a concept, even more than seventy-five years after Pigou (1920) and more than thirty-five years after the work of Walters (1961) and Vickrey (1963), is still used principally in regards to congestion problems.

Surveys of road pricing include the works of Morrison (1986), Johansson and Mattsson (1995), and Verhoef (1996) (see also Arnott et al. 1994).

Recently, however, there has been a growing interest in exploring road pricing not only as a tool for congestion management but also as a tool for environmental management since there has occurred an increase in environmental awareness both on the part of citizens as well as government officials.

Indeed, the interest in utilizing road pricing as a policy instrument is now being investigated in such areas as the reduction of environmental effects including global warming, as well as noise abatement, and accident reduction (see Verhoef 1996; Button and Verhoef 1998, and the references therein).

Moreover, governments have introduced a variety of legislation that has spurred the further development of policy instruments aimed at pollution reduction.

In 1955, the United States Congress passed legislation in order to tackle the policy problem of increasingly polluted air (cf. Clean Air Act 1955).

However, the legislation was primarily focused on supporting research into air quality issues and the next decade and a half, although filled with legislative activity, did not yield much practical impact.

The Clean Air Act Amendments of 1970 signaled a new thrust in the United States, with the federal government playing a more significant role. This led to the creation of the United States Environmental Protection Agency (EPA) with the mission of controlling the emission of pollutants into the air.

The Clean Air Act and, in particular, its amendments (cf. CAAA 1990, US Department of Transportation 1992a) addresses two classes of pollutants – *criteria* pollutants and *hazardous* pollutants. The seven criteria pollutants are: sulfur dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, ozone, lead, and total suspended particulates. These pollutants are commonly found in most parts of the world and are regarded to be dangerous in high concentrations. The seven hazardous pollutants listed by the EPA in the United States are: asbestos, beryllium, mercury, arsenic, vinyl chloride, benzene, and radionuclides. Even limited exposure to these pollutants can be harmful.

Governmental Environmental Standards

The EPA has set legal standards, known as *ambient air quality standards*, for each criteria pollutant.

The *primary standard* has the earliest deadline for compliance and is set for each pollutant separately.

The *secondary standard* governs other aspects such as aesthetics and, hence, only two pollutants, sulfur dioxide and total suspended particulates, have separate secondary standards.

In the United States, hence, the 1990 Clean Air Act Amendments (cf. US DOT 1992a) and the 1991 Intermodal Surface Transportation Efficiency Act (US DOT 1992b) have stimulated a growing interest in the development, analysis, and application of environmental transportation policies.

Transportation Control Measures

Various transportation control measures have also been applied around the globe in such cities as Athens, Amsterdam, Barcelona, and Munich, as well as urban road pricing, as already mentioned, in Singapore (see, e.g., Jones and Hervik 1992; Goddard 1997; *The Economist* 1997). It is becoming increasingly evident that transportation policies to reduce pollution must be coupled with congestion reduction.

Indeed, this point has been reiterated by many studies (cf. Lawson et al. 1990; Ingalls 1989).

Environmental Policy Instruments

The interest in pollution reduction, in general, has given rise to a large body of literature in the field of environmental economics and in the regulation of externalities.

Indeed, the optimal solution from a firm's or other pollution source's perspective does not coincide, typically, with the optimal solution from society's point of view. In this part of the lecture, I discuss policy instruments which have had a thorough investigation in the literature and which have also been implemented in practice.

For a survey on environmental economics, see Cropper and Oates (1992).

The emphasis here is on economic-incentive policy instruments which are fundamental to the models developed and studied in this book. The Table summarizes some of the policy instruments for regulating externalities that are studied in this course.

In particular, here the focus is on two fundamental economic policy instruments, that is, Pigouvian taxes and subsidies, as well as marketable pollution permits.

Such economic-incentive approaches to environmental policy and decision-making are to be contrasted with an earlier common approach to environmental regulation known as *command and control*, which was lacking in positive incentives.

The command and control aspect set the emission standards for the sources, specified how the pollution was to be reduced, for example, through the adoption of particular technologies, and no trading of pollution allowances was permitted.

Some policy instruments for regulating externalities due to transportation

Demand-side oriented policies	Supply-side oriented policies
• Marginal cost pricing • Emissions pricing • Tradable pollution permits • Mode switching	• Technology policies • Infrastructure (network design) policies

Historically, most pollution control has been in the form of a command and control approach in the form of regulation.

However, it is now being recognized that such an approach with the regulations being designed with little or no regard for the cost of abatement has not been successful.

For example, a joint report by the US Department of Transportation and the Environmental Protection Agency in 1993 noted that traditional transportation control measures aimed at decreasing motor vehicle trips, the number of vehicle miles traveled, and congestion by encouraging off-peak travel or the use of alternative transportation modes have "not generated significant air quality benefits."

The same report suggests that "economic-market-based" transportation control measures and incentives such as congestion pricing and emission charges which affect the demand for travel may be more promising for emissions reduction.

Taxes and Subsidies

Environmental taxes such as those charged to polluters are a form of economic-incentive policy instrument in that something negative, in the form of pollution, for example, is taxed in order to provide an incentive for it to be reduced.

A Pigouvian or a per-unit tax on emissions set equal to marginal social damage at the optimal level of emissions, is a particular form of pollution tax and aims to internalize the external costs imposed by the polluting source onto the victims (cf. Baumol and Oates 1988).

Although the per-unit tax was proposed in the early twentieth century by Pigou (1920), these instruments of policy control are a *new* concept in pollution control and the status quo very often is inclined to resist taxes.

In this course pricing policies are proposed, which can be interpreted as Pigouvian taxes, in the context of congested urban transportation networks, in which environmental quality standards are also imposed. Button and Verhoef (1998) provide, in their edited volume, a collection of papers that examine Pigouvian taxes, as well as other policies under the topic of road pricing.

Subsidies, on the other hand, may be granted based on the amount of pollution that is reduced. Under this approach, rather than coercing the polluters to pay a tax for exceeding a standard, the polluters are encouraged to reduce pollution, for example, by installing pollution-abatement technologies. Of course, subsidies may be used in conjunction with taxes.

Marketable Pollution Permits

The idea of pollution permits can be traced to Crocker (1966), who focused on air pollution permits, and Dales (1968), whose work was on water permits.

In this policy setting, the regulatory agency specifies a certain level of pollutants, and then issues permits, with the trading of permits triggering this system.

The marketability of permits is the main appeal of this approach.

First, this approach is cost-effective since the polluter, who faces higher pollution-abatement costs, may be able to buy additional permits in order to cover the excess emissions, whereas another polluter, who faces lower abatement costs, may be able to sell the excess permits in the market.

In the case where there are new entrants in the market, in order that the same environmental standard is maintained, the new entrants may buy permits or invest in technologies aimed at limiting emissions.

The regulatory agency can potentially release more permits into the market or buy back some permits, depending upon the level of environmental quality desired.

Montgomery (1972) provided the rigorous theoretical foundations of marketable pollution permits and proposed two systems: a system of “pollution licenses” that defines allowable pollution concentrations at a set of receptor points and a system of “emission licenses” that confers the right to emit pollutants at a certain rate at the sources.

The former system is known as the **ambient-based permit system (APS)**, whereas the latter is known as the **emission-based permit system (EPS)**.

Also, Montgomery established that markets can attain equilibrium that achieves the externally set environmental quality standards. He also explicitly recognized the **spatial nature of pollution dispersion** and introduced a diffusion matrix. Montgomery (1972) focused on *stationary* sources of pollution, that is, those which are fixed in location, as opposed to *mobile* sources of emissions, such as motor vehicles.

Nagurney and Dhanda (1996) considered both perfectly competitive firms as well as oligopolistic firms and developed variational inequality-based models to study and determine the equilibrium problems.

Nagurney, Dhanda, and Stranlund (1997) subsequently proposed a multiproduct, multipollutant, perfectly competitive firm model with pollution permits.

Nagurney and Dhanda (1997a) devised a variational inequality framework for the study of multiproduct, multipollutant, oligopolistic firms in the presence of marketable pollution permits with opportunities for investment in production technology and/or emission/abatement technology.

Nagurney and Dhanda (1997b) then addressed compliance versus noncompliance behavior in oligopolistic markets, again, with ambient-based pollution permits. Nagurney and Dhanda (1997c), in turn, considered oligopolistic markets and pollution permits in the presence of transaction costs.

The system of marketable pollution permits was given credibility as an **economic incentive-based environmental regulation approach** to address pollution by Title IV of the 1990 amendments to the Clean Air Act (CAAA). Under Title IV, for example, electricity generating facilities can trade allowances or permits for the emissions of sulfur dioxide.

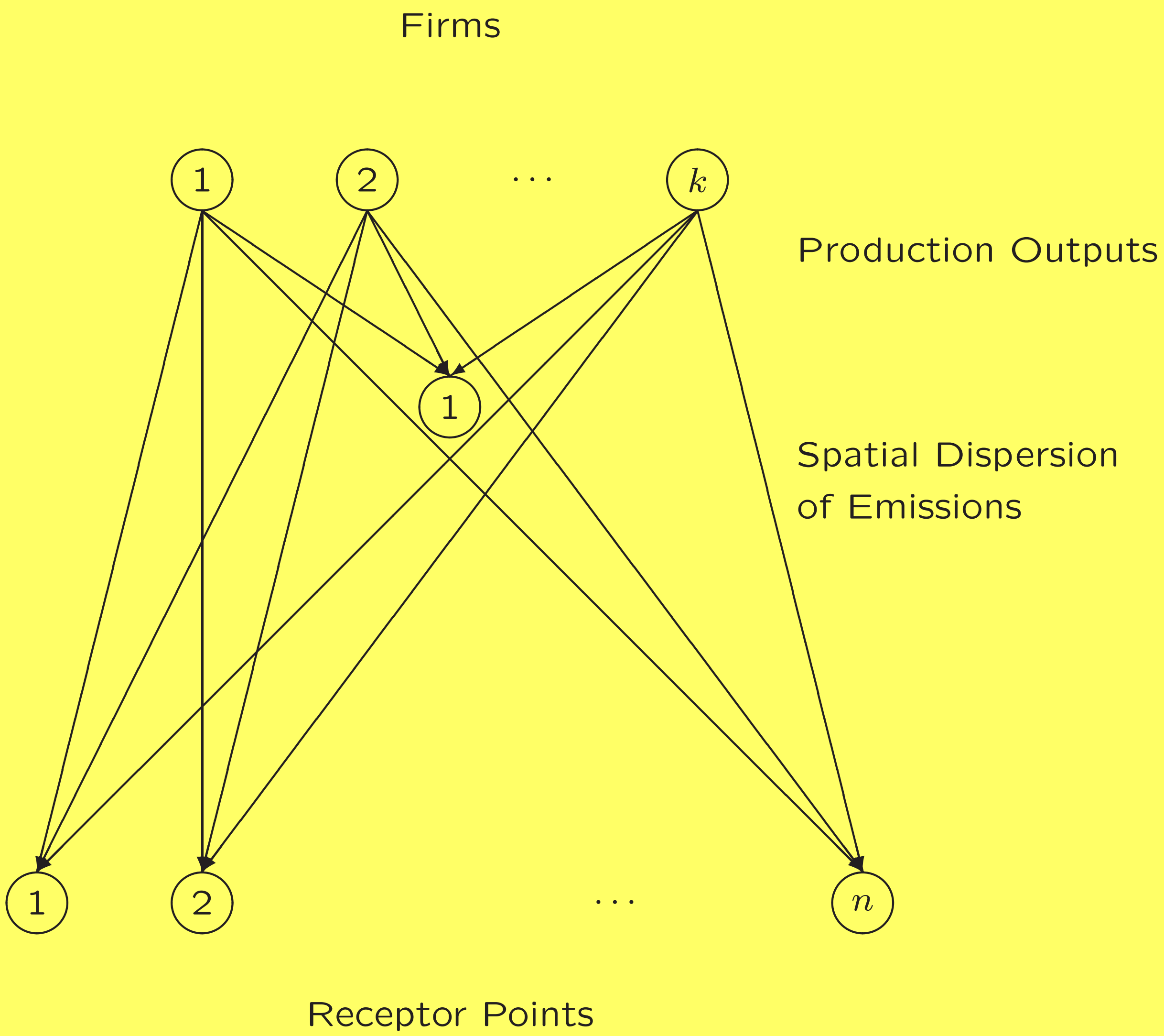
The principal appeal of the economic incentive approach versus the traditional command and control approach is that the former system encourages firms to employ pollution control technologies. For example, a firm participating in a permit market may install emission reducing technologies, lower its level of emissions, and sell the excess entitlements of permits for revenue.

For a detailed discussion of other advantages of permits, see Tietenberg (1985), Baumol and Oates (1988), and Pearce and Turner (1990).

Nagurney, Ramanujam, and Dhanda (1998) were the first to rigorously construct a system of pollution permits for congested transportation networks. They also considered the issue of compliance versus noncompliance.

The book by Dhanda, Nagurney, and Ramanujam (1999) on *Environmental Networks* describes a variety of economic-incentive-base approaches for emission abatement through the prism of *environmental networks*, which provide a graphical and, hence, visual approach to the study of economic activity and its environmental affects.

In the next Figure, a graphical depiction of pollution dispersion by firms is presented in a network format.



Spatial dispersion of emissions due to firms

A practical application of tradable permits in transportation was the vehicle quota system in Singapore (Koh and Lee 1994).

Another example of a tradable permit system related to transportation is the lead trading program in the United States, which was designed to reduce lead in large refineries (Hahn 1989).

Button (1993) considers the United States Corporate Average Fuel Economy Standards (CAFE) program, introduced in 1975, as another example of tradable permits in the transportation sector, albeit one in which the trading is internal to a firm, rather than external.

Goddard (1997) describes the applicability of a permit system for transportation in the Mexico City area. *Feebates*, an alternative, although related, incentive approach for pollution reduction, denotes a system of fees and rebates applied to new cars and trucks based on their emission rates, fuel efficiency, or other characteristics (see Train, Davis, and Levine 1997).

It is important to mention that the Clean Air Act and its amendments have resulted in major progress in terms of the reduction in ambient air pollution concentrations in the United States, as documented by the Council on Environmental Quality (1991).

Indeed, according to their report, during the period between 1978 and 1990, the ambient concentration of nitrogen oxides declined by 24%, that of ozone by 27%, that of sulfur dioxide by 39%, and that of carbon monoxide by 42%.

Furthermore, an Environmental Protection Agency report (cf. US EPA 1997) analyzing the Clean Air Act and its amendments in the two decades following 1970 suggested that each dollar of compliance cost is estimated to have generated approximately $15.60 in such areas as agricultural production, property values, and human health.

Unique Transportation Network Characteristics

A transportation network may be viewed as an economic system in which the demand side corresponds to potential travelers or consumers of the network, whereas the supply side is represented by the network itself, with incurred prices corresponding to the travel costs.

As already noted, two negative externalities associated with such networks include both congestion and pollution.

Presently, almost all urban regions in the United States are faced with inducing major changes in current transportation choices in order to achieve the objectives of reducing congestion and improving air quality.

In Europe, on the other hand, the European Commission's Green Paper on *Fair and Efficient Pricing* (Commission of the European Communities 1996) reflects the current reassessment of transportation policy and states that "transport policy is at a crossroads."

Indeed, since it has become increasingly clear that enhanced emission control technologies may not be sufficient to achieve air quality goals, interest in how policies can affect the utilization of transportation networks and the associated negative effects has increased.

Since **transportation networks are complex systems** in which individuals interact typically unilaterally but, nevertheless, affect the cost and travel time of others, policies which fail to incorporate the behavior of the users of the system may lead to contrary results from that intended.

Indeed, this possibility has been increasingly noted. For example, Hall (1995), in discussing a class of transportation policies known as transport control measures (TCMs), has noted that better understanding of actual behavior coupled with new scientific and technical observations of how emissions actually relate to patterns of vehicle use has challenged the conventional wisdom that reduced vehicle miles travelled and/or improved traffic flow means less congestion and cleaner air.

TCMs are a broad grouping of diverse alternatives that seeks to modify light-duty vehicle use either by increasing the cost in terms of money or time, or by providing improved, that is, lower, cost or more convenient, transportation alternatives.

Sevigny (1998) notes that her design of an emission tax for automobiles for pollution control could, in fact, have the perverse consequence of increasing vehicle emissions by encouraging more short trips to reduce taxable vehicle miles traveled. Further, she notes that a trip generation model, which would also account for trip cost (and, hence, require the network topology and travel cost structure) would be a useful addition to her policy modeling schema.

Indeed, as regards transportation policies, their effectiveness can only be determined when the influence on human behavior (and the interaction between fuel/vehicle technology, if any) is also calculated.

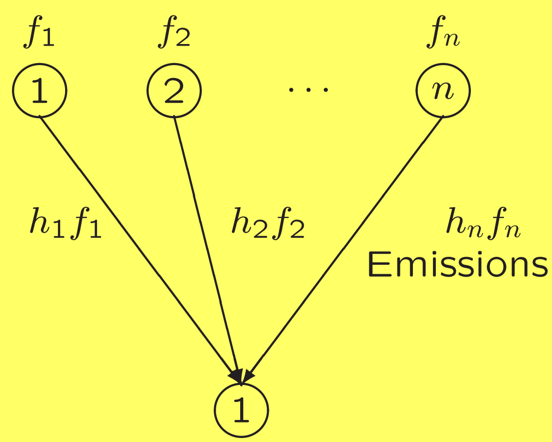
A Transportation Research Board (1995) study examined the effect of highway capacity improvement on motor vehicle travel, energy use, and emissions and found that the relationships among them are highly complex because of secondary effects on travel demand.

Another Transportation Research Board (1997) report focused on transportation in the context of a sustainable environment and noted that there is a lack of and a need for policy research on this topic.

In this course, policy models for emission and/or congestion abatement are developed, which determine flows on the transportation network endogenously, operating under a particular behavioral assumption.

The key in the calculation of the mobile source emission estimates (see Figure) is the relationship that the volume of emissions is equal to the product of a composite emission factor times the vehicular activity at the link levels (cf. DeCorla-Souza et al. 1995), which is also herein used in the technical analyses.

$$G = [N, L]$$



Transportation Network

Receptor Point

Spatial dispersion of vehicular emissions

Emission Factor

The emission factor may be interpreted as a term in the diffusion matrix introduced by Montgomery (1972) in his marketable pollution permit work. Indeed, in the Figure, the spatial dispersion of vehicular emissions is represented as a network where the flow on the links are then converted into emissions (after multiplication by an emission factor on each link).

In this case, there is a single receptor point associated with the emissions.

On the other hand, in the case of multiple receptor points, one would need to add additional lower nodes to the network on the right of the figure and to also draw links from the upper nodes to those new nodes.

Note that in the case of transportation networks, in contrast to firms, the emissions are now due to mobile rather than stationary sources.

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