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# Policy for the adoption of new environmental monitoring technologies to manage stock externalities ☆

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ABSTRACT

With the development of modern information technologies, relying on nanotechnologies and remote sensing, a number of systems can be envisaged that allow for monitoring of the negative externalities generated by producers, consumers or travelers—road pricing schemes or individual emission meters for automobiles are two examples. We analyze a dynamic model of stock pollution when the regulator has incomplete information on emissions generated by heterogeneous agents. Our contribution is to explicitly study a decentralized policy for adoption of monitoring equipment over time. We determine the second-best tax rates, the pattern of monitoring technology adoption, and identify conditions for the voluntary diffusion of monitoring technologies over time. Simulations show the welfare gains compared to alternative policies.



## 1. Introduction

Some of the major environmental problems of our time are stock externality problems, including contamination of water bodies by accumulating salt and chemicals, climate change, other air pollution problems where accumulating pollutants damage health or property, deforestation and loss of biodiversity. Frequently, the damaging activities cannot easily be attributed to individual agents, which is a challenge to policy making. However, applications of new technologies including computers and the internet, wireless telephony, remote sensing, and geographic information systems, enable the introduction of increased numbers of monitoring systems to identify externality sources. In some cases, e.g., road pricing in Singapore, we already see instantaneous monitoring of road use that generates negative externalities (congestion and air pollution). The new technologies may require large investment in infrastructure, as well as in individual units of equipment. While in some cases, individual agents may need to invest in new technologies, in others they may rent environmental monitoring equipment,[1] and in other situations polluters may subscribe to third-party monitoring services.

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[1] For example, companies such as Enviro-Equipment, Inc (http://www.enviroequipment.com/), Ashtead technology (http://www.ashtead-technology.com/us/), Satellite Imaging Corporation (http://www.satimagingcorp.com/services.html) and Fondriest Environmental (http://www.fondriest.com) rent either environmental monitoring equipment or monitoring services for various applications.

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We analyze policies leading to the adoption of new monitoring technologies over time to control stock externalities. The analysis centers on individual agents' incentives to adopt monitoring technology, their changing behavior over time, and the trade-off between a decentralized policy and a policy consisting of mandatory monitoring. Our contribution is to identify an optimal decentralized policy for inducing the adoption of monitoring technology and to analyze the time paths of the adoption process and of key economic and environmental variables. The principle behind this optimal policy when monitoring is feasible but costly is that each agent is assumed "Guilty until Proven Innocent" as proposed by Swierzbinski [22]. Specifically, agents are required to pay the maximum pollution fee, and it is up to them to prove that they are entitled to a refund. Several existing or proposed regulations of pollution or damages are based on this principle. For example, the California Department of Pesticide Regulation establishes default inhalation rates for children and adults for assessing the exposure rates to chemicals and those are imposed in cases when the applicator cannot provide her own assessments. The regulation order for the California Low Carbon Fuel Standard Regulation states that the carbon content of fuels will be verified at the user's expense for every fuel category, otherwise a "conservative" default value is assumed.[2]

The scheme that we propose for delegation of monitoring adoption has potentially important applications since it results in diffusion of monitoring technology over time through voluntary adoption of the new technology. One potentially relevant application is the use of smart dust in monitoring and tracing pollution to its source [18,23]. Identity preservation is becoming part of current food safety policies that rely on the tracing of a faulty product towards its origin (source), and identity preservation through the tagging of molecules of dirty inputs can now be envisaged using nanotechnologies. Identity preservation applied to polluting inputs such as pesticides and chemical fertilizers would enable the regulator to trace the source of pollution in case of environmental degradation and will have interesting applications for water quality policy.

The paper relates to several bodies of literature: the literature on threshold models of technology adoption, the literature on stock externalities and the literature on pollution regulation with costly information. The threshold model of technology adoption was first introduced by David [2] to provide a stronger micro-economic foundation to the Griliches [9] model; it assumes that agents are heterogeneous (for example in size) and that profit maximization implies a threshold in the quality parameter, after which it becomes profitable for the individual agent to adopt. Technology diffusion over time will then depend on the distribution and dynamics of the characteristic that determines heterogeneity among adopters [20,21]. Here we use a threshold model to study the diffusion of new monitoring technology for stock externalities. Major environmental problems, such as climate change, water pollution, soil erosion and buildup of pesticide resistance are frequently stock externality problems [7], and moreover they are usually caused by heterogeneous sources [12,26]. Thus, for an efficient design of policies to control stock externalities both time and heterogeneity dimensions of these problems should be considered [24]. The buildup of the pollution stock can be modified through changes in production practices, by reducing input use, by decreasing the number of agents that operate in the economy, and through adoption of modern conservation or precision technologies that enhance input use efficiency [14].

The last body of research that we contribute to is the literature on pollution regulation with costly information. Many of today's most important pollution problems are plagued by costly information on individual emissions. Examples include traffic emissions and agricultural runoff into water, such as nitrogen or pesticide leaching from fields. Carbon emissions from stoves and burners are another example. The diffuse pollution from many small sources whose individual emissions are unobservable constitutes a nonpoint source pollution problem. Following Holmstrom [13], the first-best solution is a tax equal to the full social marginal cost on each polluter [10,11,15,19,25]. In some cases, it can be difficult to do so, in particular when polluters do not realize their impact on the aggregate measure of pollution [1], or when the regulator cannot be certain about the level of cooperation within the group [16]. Investing resources in improving the monitoring of individual emissions may thus be worthwhile. Xepapadeas [27] showed how risk-averse polluters may prefer to pay an emission tax rather than a variable ambient tax. Millock et al. [17] proposed discriminatory treatment for agents who invest in monitoring equipment and pay a tax proportional to the pollution they generate, while others will pay a fixed tax. Thus, the definition of nonpoint source pollution will evolve as the social cost of pollution changes.

The first papers to study the dynamics of investment in monitoring have focused on the regulator's centralized decision of investment in her stock of knowledge about the pollution process [4,5,8,27]. Dinar and Xepapadeas [5] develop a model of the regulator's information acquisition for regulating groundwater in irrigated agriculture. Monitoring is treated as the regulator's stock of knowledge (information), which can be added to by investments in geographical information systems (GIS), or through study of the soil conditions in the region and other factors that affect transport and fate. There is thus no individual decision to adopt a monitoring technology at each individual source. The model shows theoretically and empirically [4] that it is more efficient to direct resources to investment in knowledge capital about the emissions process than to try to monitor input use in order to levy input taxes as a proxy to pollution taxes. Farzin and Kaplan [8] also model monitoring as an effort on behalf of the regulator to improve a stock of knowledge capital, including knowledge of pollution transport and fate. They analyze the problem of a private or public manager that must target abatement resources in a National Park area with a fixed budget, and where the sediment load (pollution) is a function of unknown site-characteristics. Their simulations confirm that information acquisition improves the budget allocation of the National Park Manager and hence reduces expected damage compared with the case of an ex ante uniform prior distribution of

[2] The California Low Carbon Fuel Standard Program, Section 95486, accessed at http://www.arb.ca.gov/regact/2009/lcfs09/lcfscombofinal.pdf.