Enforcing Environmental Regulation: Implications of Remote Sensing Technology

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<u>Abstract</u>

We review economic models of environmental protection and regulatory enforcement to highlight several attributes that are particularly likely to benefit from new enforcement technologies such as remote sensing using satellites in space. These attributes include the quantity and quality of information supplied by the new technologies; the accessibility of the information to regulators, regulatees, and third parties; the cost of the information; and whether the process of information collection can be concealed from the observer. Satellite remote sensing is likely to influence all of these attributes and in general, improve the efficacy of enforcement.

Key Words: environmental regulation, new technologies, remote sensing

JEL Classification Nos.: Q2, Q28

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ENFORCING ENVIRONMENTAL REGULATION: IMPLICATIONS OF REMOTE SENSING TECHNOLOGY

Molly K. Macauley[1] and Timothy J. Brennan[2]

1. INTRODUCTION AND EXECUTIVE SUMMARY[3]

An important potential benefit of emerging telecommunications technology involves the enhanced ability to detect environmental pollution using remote sensing devices. Detailed information can be collected by existing and proposed systems of satellites, aircraft, and automated ground monitors and transmitted through telecommunications networks back to a central location for analysis and evaluation. Data collected by proposed commercial, civilian satellite systems planned for launch in 1996 and beyond will be particularly precise, with sophisticated spatial, spectral, and temporal resolution.

The environmental benefits of these technologies are obvious. They are capable of not only measuring air and water emissions, soil contaminants, and other indicators, but also of helping to provide the "big picture" in assessing the ecological context of these factors--that is, helping to answer the "so what" question as to the effects of pollution on humans and the environment.[4] In addition, emerging remote sensing technologies can improve understanding of, and in many cases reduce, the range of uncertainty regarding the extent of environmental degradation.[5] The new technologies may also reduce the costs of compliance with and enforcement of both domestic regulations and international agreements concerning the environment. Such finely tuned monitoring has several implications for the way in which the

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[4] For example, automated ground monitors combined with aircraft photos are being used to facilitate monitoring of water quality. See "Kansas City Builds a GIS to Defray Costs of Clean Water Act Compliance," Geo Info Systems, June 1995. As another example, ground-based remote sensing of auto tailpipe emissions has been conducted in pilot projects in several urban areas. See R. Brooks. "California Report Recommends Drive-By Sensor," Ward's Engine Update, 1 December 1992; Hughes Environmental Systems, Inc., "Feasibility Study for the Use of Remote Sensors to Detect High Emitting Vehicles," Final Report prepared for the South Coast Air Quality Management District (California), 22 December 1992. For general discussion of using satellite data for monitoring international environmental agreements, see B. Berkowitz, "Use of Intelligence Data for Environmental Monitoring: Summary of Meetings Held by the Council on Foreign Relations," May 1992 (mimeo).

[5] For instance, see D. Judd, "Risk Assessment, Uncertainty Analysis, and Other Fancy Lies," Earth Observation Magazine, August 1994.

Environmental Protection Agency and other decision makers regulate. For instance, the data may permit closer monitoring of information that is self-reported by regulatees and play a key role in adjudicating environmental lawsuits and disputes.

In this paper we focus on enforcement properties of space-based remote satellite sensing technologies (hereinafter, RSS) with respect to their implications for how regulatory policy is made and conducted.[6] These issues include the extent to which RSS is likely to reduce significantly the costs of monitoring, compliance, and enforcement for regulatees, regulators, or both; whether the technologies affect incentives for regulatees to self-report accurately;[7] and other ways in which RSS may change the structure and implementation of regulation. We assess RSS with respect to the environmental conditions it can sense; its timeliness, accuracy, and reliability; the accessibility of RSS data to regulators, regulatees, and third parties; the implications of the ability of RSS to operate without the awareness of the observed; and, to a limited extent given the uncertainty and scarcity of the data, the cost-effectiveness of RSS compared with alternative sources of information.[8]

In our view, the growing role of new remote satellite sensing technologies in environmental regulatory enforcement makes these economic, political, and legal questions increasingly important. Research at this time, before these questions become critical, may enhance the effectiveness of environmental regulation. Our conclusions support this perspective as they suggest several directions for regulatory policy. Specifically, we find that:

- While it is not clear the extent to which emerging RSS technologies will detect specific emissions in some media (such as some types of gas emissions), high resolution data can provide a context for understanding the damages associated with environmental pollution. In turn, this information confers at least three benefits for environmental enforcement: it can assist in more accurately assessing damages, in improved targeting of enforcement and remediation, and in providing information

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[6] We thus extend the literature on monitoring and enforcement (e.g., see C. S. Russell, W. Harrington, and W. J. Vaughan, *Enforcing Pollution Control Laws* (Washington, DC: Resources for the Future, 1986); W. Harrington and M. Macauley, "The Value of Information and the Cost of Advocacy," Resources for the Future, Washington, DC: Resources for the Future, June 1995 (mimeo).

[7] The relevant literature on self-reporting is informative but sparse. See J. Harford, "Self-Reporting of Pollution and the Firm's Behavior under Imperfectly Enforceable Regulations," *Journal of Environmental Economics and Management* 14 (1987): 293-303; A. S. Malik, "Self-Reporting and the Design of Policies for Regulating Stochastic Pollution," *Journal of Environmental Economics and Management* 24 (1993): 241-257; L. Kaplow and S. Shavell, "Optimal Law Enforcement with Self-Reporting of Behavior," *Journal of Political Economy* 102 (1994): 583-606.

[8] We do not do this in this study, but, for instance, the information-related gains in the efficiency of emissions trading markets from reduced transaction costs and better monitoring could be estimated (at least in theory, and with data where available) using the usual surplus parameters. Along the way, a useful question to investigate would be whether the private sector is likely to capture the "public good" gains from reducing transaction costs by setting up emissions trading markets and conditioning their use on participant's willingness to subject themselves to observation systems of one sort or another. If so, government intervention may not be necessary to take advantage of the gains information technology may achieve in emissions markets.

for the decision whether to use quantity- or tax-based means of pollution control. In addition, more accurate information such as that offered by high resolution RSS may minimize punishment of those who do not violate regulations.

- The accessibility of new RSS data to all parties--regulators, regulatees, and third parties--may facilitate private enforcement as a substitute for public policy by reducing transactions costs. Regulatees may also use RSS data for their own self-reporting efforts, which if credible, can substitute for inspections and monitoring. Credibility of the data may be heightened by its public accessibility. Accessibility also increases the opportunity for even-handedness in monitoring and enforcement, in treating equally all sources that compete with each other in product markets.
- If new RSS data represent a more cost-effective source of information compared with alternative data sources, then repeated measurements might be economically taken using RSS, improving accuracy and the likelihood of detection of violations of environmental regulations. Repeated measurements may also improve detection of polluting activities subject to random fluctuations due to climate or other factors. Lower monitoring costs can also boost any deterrence effects of enforcement by making enforcement easier, and this approach may be an alternative to fines. In addition, more cost-effective information may permit greater use of economic incentive based approaches to regulation (and enforcement) rather than command-and-control approaches, which are theoretically less efficient.
- Finally, the opportunity for RSS to serve as a concealed means of observation can increase both the likelihood of detection and the costs of concealment of activities on the part of the observed entity, improving the effectiveness of enforcement actions. We note, however, that the operating parameters of RSS are a matter of public record and therefore make it possible for observed entities to conceal their actions when a spacecraft is expected to be overhead.

The remainder of the paper is organized as follows. The next section describes existing and most importantly, emerging RSS technologies. The third section reviews economic analyses of environmental protection and regulatory enforcement, to indicate what factors are most important in deciding how RSS is likely to influence these activities. The fourth and fifth sections combine our review of the regulatory models and our assessment of RSS technology to draw inferences about future policy directions for enforcing environmental regulations.

2. REMOTE SATELLITE SYSTEMS: TECHNOLOGY OVERVIEW

In this section we first describe remote sensing technology and then discuss remote satellite systems, including both current technology and new technologies expected to be available beginning in late 1996. We focus on those aspects of the technologies that are most relevant to environmental enforcement.

2.1 Background[9]

Quite generally speaking, remote sensing is the act of observing an object at some distance removed from the object. Two of the most frequently cited definitions are offered by Lillensand and Kiefer and by Campbell in their textbooks on remote sensing. According to Lillensand and Kiefer:

> Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.[10]

Campbell's definition more specifically addresses the application of remote sensing to studying the earth:

> (Remote sensing is) the science of deriving information about the earth's land and water areas from images acquired at a distance. It usually relies on measurement of electromagnetic energy reflected or emitted from the features of interest.[11]

Under either definition, remote sensing can include a host of technologies, from aircraft observations and ground-based devices such as sensors on a smokestack, to space-based observations.

2.2 Introduction to RSS

Our focus is on remote sensing using space-based observations. There are two general types of RSS observations, electro-optical and radar. The optical systems use either photographic or electromechanical sensing devices, and until recently, the bulk of space-based imagery has been the province of these electro-optical remote sensors. Radar imaging systems began with experimental sensors in the late 1970s and now include operating sensors launched in 1995. Both electro-optical and radar technologies may be situated on aircraft, spacecraft, or on the ground, but again, our discussion centers on space-based technologies.

RSS technologies are usually described based on their spatial resolution. A conventionally used, rough "rule of thumb" for judging spatial resolution is the following: at ten meters, an airport runway and its navigation markings are discernible; at five meters, aircraft and large objects being loaded or unloaded can be identified; at one meter, automobiles can be seen.

Photographs are the most typical and traditional means of remote sensing. The photos can be two- or three-dimensional (for three dimensional, or stereo photos, the camera obtains

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[9] Much of this section is based on S. A. Drury, *A Guide to Remote Sensing* (New York: Oxford University Press, 1990).

[10] T. M. Lillesand and R. W. Kiefer, *Remote Sensing and Image Interpretation* (New York: John Wiley and Sons, 1987).

[11] J. B. Campbell, *Introduction to Remote Sensing* (New York: Guilford Press, 1987).

overlapping frames which are then exposed in sequence). The photos can be in black and white (panchromatic), natural color, or infrared. The spatial resolution or sharpness of the photo depends on the camera lens, film, and distance from the lens to the object of interest. Most satellite remote sensing currently available to the civilian sector (as opposed to the defense sector) has spatial resolution in the neighborhood of five to thirty meters. Of particular interest in our assessment here, however, are proposed civilian systems that will have resolution as fine as one to three meters. Some commercial firms are planning resolution even better than one meter.

Electromechanical devices refer to detectors that sense the radiation that is naturally reflected from the surface of an object. Such devices include line scanners and charge-coupled devices. Line scanners are mirrors which collect radiation from the surface of an object as the mirrors sweep across it. Charge-coupled devices, or CCDs, consist of arrays of thousands of tiny, light-sensitive detectors which measure radiation directed onto the arrays through a system of lenses. The devices record the information in either analog or digital mode; digital data are particularly useful in that they can be readily processed, enhanced, and analyzed by computers. An advantage of electromechanical devices that facilitates analysis of the data they collect is that the orderly array of lines and image elements, or pixels, that they produce and their collection of different wavebands of radiation from the same portion of the surface means that the data from all wavebands of the radiation are exactly registered to one another.

Passive microwave imaging uses antennas to scan radiation from the microwave region of the spectrum. The resolution of an image from such a system is approximately the wavelength divided by the antenna diameter. Historically, since there has been a physical limit to the size of a portable antenna mounted on a spacecraft, and because microwave wavelengths are in millimeters to centimeters, the spatial resolution at orbital altitudes has been quite coarse (on the order of ten to thirty kilometers). Recent technological advances, together with public policies that now permit use of these technologies for non-military related applications, have greatly increased the spatial and spectral resolution available. As mentioned above, the spatial resolution of commercial satellites planned for launch beginning in 1996 is as detailed as one to three meters. New hyperspectral sensors on commercial satellites will be able to distinguish very fine gradations of the spectrum. Regardless of these advances, however, a disadvantage of passive microwave imaging for some applications is that it is affected by weather (clouds obscure the imaging) and cannot operate at night.

Active microwave or radar imaging directs energy towards the surface; energy reflected from the surface then travels back to the sensor. The time taken for the energy to travel back is a very accurate measure of distance between the sensor and the object. Space-based radar is useful for producing three-dimensional information; data about the height of the ocean surface, for instance, can be the basis for deductions about bathymetry and the gravitational field or about wind speeds. Radar imaging is unaffected by weather and can operate during night or day. However, a major problem with radar is that the beam of energy spreads out with distance. For acceptable resolution, the antenna must be quite large.

Synthetic aperture radar (SAR) solves this problem by exploiting the Doppler effect that shifts the frequency of returned energy. The Doppler history of the returned energy is recorded and after additional processing yields data of resolution equal to or greater than that obtained from real aperture radar. SAR permits a short antenna to mimic one up to several hundred meters long. Even with SAR, however, the data rates and processing requirements can be quite high, taxing the capability of both the spacecraft and the data communication downlinks. Advanced in data compression and bandwidth utilization techniques have begun to alleviate these problems.

2.3 Existing RSS Systems

While these technologies can be and have been ground- and aircraft-based when applied to the problem of environmental regulatory enforcement, their use for this purpose from the vantage point of space-based platforms is relatively recent. Space remote sensing in the civilian sector began in 1963 with programs under the aegis of the National Aeronautics and Space Administration (NASA) and the National Oceanographic and Atmospheric Administration (NOAA). The programs focused largely on experimenting with how to build and launch the spacecraft and sensors; record, transmit, and process the data; and interpret the data. Environmental applications of these early RSS systems typically were to record land use, monitor the health and yields of some agricultural crops and forest stands, and identify geologic formations useful in oil, gas, and non-fuel minerals exploration.

Since the advent of these experimental programs in the 1960s and 1970s, additional civilian remote sensing spacecraft have been launched by the U.S. government and foreign governments.[12] All of these current systems operate at such large-scale resolution (spatial, spectral, and temporal) that they have tended not to be used for observing details such as chemical interactions, air particulates, and other small scale phenomena. The systems have also been less useful for phenomena that are best observed in continuous time. Rather, the niche for RSS to date has been in observing land use, large topographic features, and other grosser-scale information at more discrete time intervals. Aircraft (including remotely piloted aircraft, or drones), small rockets, balloons, and *in situ* sensors have been the preferred technologies for the smaller scale measurements, and real-time, continuous monitoring has been the province of *in situ* sensors.[13]

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[12] In addition, some RSS imagery collected by national security satellites has been released for the purpose of environmental analysis. See, for example, B. Gertz, "Gore Touts Use of Spy Photos for Fighting Global Pollution," *The Washington Times*, 25 February 1995: A5; A. Lawler, "Spy Photos Come in from the Cold," *Science* 267 (3 March 1995): 1260. See also discussion in B. D. Berkowitz, The Use of Intelligence Resources for Environmental Monitoring: A Critical Issues Report by the Council on Foreign Relations, February 1993 (mimeo). There are two additional sources of RSS information which we do not focus on in this study: weather satellites, and sensors flown on the U.S. space shuttle. Weather satellites provide data about atmospheric conditions, ocean temperatures, and ocean turbidity, for example. Sensors flown on the space shuttle include electro-optical and SAR devices.

[13] W. E. Leary, "Designers Plan Drones to Probe Atmosphere," *The New York Times*, 31 March 1992: c1, c10 offers good discussion of the relative advantages of drones, balloons, and other techniques.

At the present time, civilian remote sensing systems include the U.S. Landsat system and systems operated in France, Russia, India, and Israel. Russia, Canada, Japan, and a joint venture by several European nations operate synthetic aperture radar systems. In most cases, the systems are directly or indirectly financially backed by governments. For example, Landsat is owned by the U.S. government but operated by a private company, the Earth Observation Satellite Company (EOSAT). Radarsat International, Inc. of Vancouver, British Columbia owns the rights to the imagery produced by the Canadian Radarsat system. Radarsat is the first spacecraft designed for the commercial radar imagery market.

2.4 Emerging RSS Technologies

Only in the past few years have RSS technologies begun to advance sufficiently, at low enough cost and with approval from national security agencies of the civilian use of high resolution imagery, to make space-based sensing useful for a wide variety of environmental regulatory enforcement activities.[14] New RSS technologies promise such improved resolution that many experts claim the technologies will revolutionize the process of environmental regulation.

Table 1 lists proposed new RSS systems. As of February, 1996, seven United States companies, representing medium to large corporations, have been licensed to deploy and operate commercial satellites with high resolution. Initially their offerings will be data collected by electro-optic sensors. A three-meter resolution satellite, EarlyBird, is scheduled for launch late in 1996. It is owned and operated by EarthWatch, a company formed by the merger in 1995 of Ball Aerospace and Technologies Corporation and WorldView Imaging Corporation. WorldView was the first company ever to receive a license to operate a commercial remote sensing satellite. Another EarthWatch satellite, QuickBird, is scheduled for launch in 1997 and will have one-meter resolution. Other licensed companies include Boeing, which plans to launch a ten-meter spacecraft; GDE Systems, with a one-meter system; Motorola, with a ten-meter system; Orbimage, Inc., a subsidiary of the Orbital Sciences Corporation, with one-to-two meter and four-meter spacecraft; and Space Imaging Incorporated, a spin-off company of Lockheed Martin Corporation, which plans to operate a three-to-five meter spacecraft and another spacecraft at better than one meter. Lockheed was the first company to receive a license to operate a spacecraft at one-meter or better.[15]

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[14] Two policies have facilitated commercial development of high resolution RSS. One is the 1992 Land Remote Sensing Policy Act, and the other is Presidential Directive-23. The 1992 Act encourages commercial development and clarifies the licensing process for the satellites. PD-23 clarifies national security policy towards the commercial RSS industry, generally permitting it to operate with minimal restrictions.

[15] There is significant speculation in the remote sensing industry and among decision makers as to how many companies the remote sensing market can support. Will the industry tend to be monopolistic, or more fully competitive? GDE and Boeing, for instance, are involved in a consortium, Resource21, planning to deploy a satellite system to monitor crop conditions for the agricultural community. This question of industry structure is outside the scope of our present study, but we realize that it is an important question for data pricing and access.

Table 1. Remote Sensing Satellites Currently Planned for the Next Decade

Country	Owner/ Objective	Program	Launch Date	Instrument Type	Resolution in Meters P	M	R	# Color Bands
France	G/O	Spot 5B	'04	P&M	5	10		4
U.S.	G/O	EOS AM-2 /L-8	'04	P&M	10	30		7
France	G/O	Spot 5A	'99	P&M	5	10		4
India	G/O	IRS-1 D	'99	P&M	10	20		4
U.S.	C/O	Space Imaging	'98	P&M	1	4		4
Korea	G/O	KOMSAT	'98	P&M	10	10		3
U.S./Japan	G/O	EOS AM-1	'98	M	15	15		14
U.S.	G/O	Landsat-7	'98	P&M	15	30		7
ESA	G/O	ENVISAT	'98	R			30	0
U.S.	G/O	Space Imaging	'97	P&M	1	4		4
U.S.	C/O	Orbimage	'97	P	1			
U.S.	C/O	Orbimage	'97	M	4			
France	G/O	Spot 4	'97	P&M	10	20		4
U.S.	C/O	EarthWatch	'97	P&M	1	4		4
U.S.	C/O	EarthWatch	'96	P&M	3	15		3
U.S.	C/O	GDE	'99		1			
U.S.	C/O	Resource21	'98	M	10			
U.S.	G/E	CTA Clark	'96	P&M	3	15		3
U.S.	G/E	TRW Lewis	'96	P&M	5	30		384
Russia	G/O	Almaz 2	'96	R			5	
Japan	G/O	ADEOS	'96	P&M	8	16		4
China-Brazil	G/O	CBERS	'96	P&M	20	20		7
Canada	G/O	Radarsat	'95	R			9	
India	G/O	IRS-1 C	'95	P&M	10	20		4
China/Brazil	G/O	CBERS	'95	P&M	20	20		7
Russia	G/O	Resours-02	'95	M		27		3
Israel	G/O	EROS	'96		2			

Notes:

Owner:
Government Funded - G
Commercially Funded - C

Objective:
Operational - O
Experimental - E

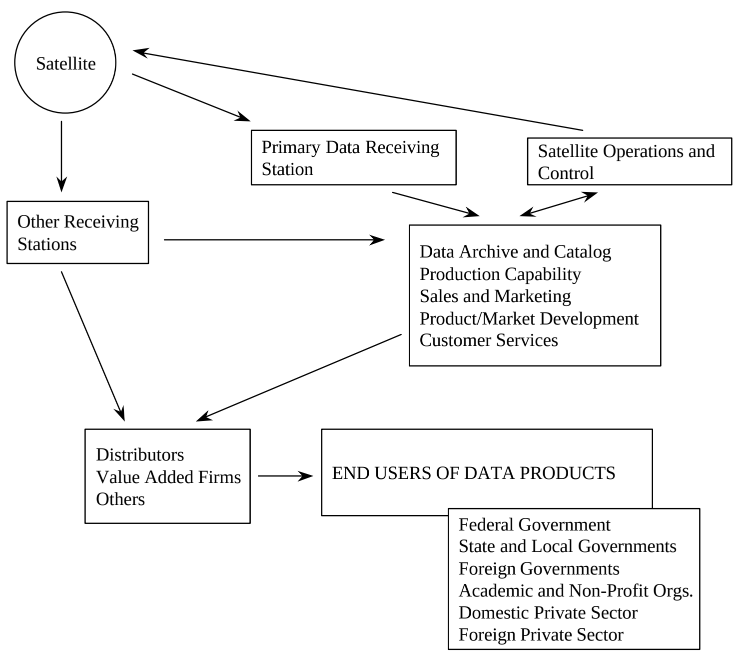
Instrument Type:
Multispectral only - M
Panchromatic Only - P
Pan and Multispectral - P&M
Radar - R

Source: U.S. Department of Commerce, Office of Air and Space Commercialization.

In addition to the U.S. spacecraft, France, Israel, India, China and Brazil (in a joint effort), Japan, and Korea plan to launch commercial remote sensing spacecraft between 1996 and 2000. The resolutions range from better than one meter to nineteen meters (the China/Brazil system). These spacecraft also include some radar technologies.

Figure 1 illustrates the typical network that companies will use to acquire and distribute data. During acquisition, the imagery is stored on-board the satellites. It is then downloaded to ground stations and sent to a master archive where it may be processed and stored. Customers buy the images, receiving them via Internet or other delivery services. Customers include licensed or franchised distributors, value-added firms that will use the imagery as input into another product (say, a map, consulting study, or other product), and actual end-use customers who will use the data for their own activities. Under some companies' arrangements, data may be sent directly to customers from the ground stations rather than be obtained only from the master archive, reaching customers in just a few hours after being collected by the spacecraft.

Figure 1. Commercial Remote Sensing Data Market Architecture



In general, the companies have contracted with international firms that will host the ground stations and in some cases serve as the regional distributors of the data. For example, EarthWatch has entered into joint partnerships with domestic and overseas firms, including Hitachi, Ltd. and Nuova Telespazio s.p.a., who will be licensed distributors of data from the EarlyBird and QuickBird spacecraft. Property rights to the data will reside with EarthWatch. In some cases, customers will also have the opportunity to task or schedule the satellite's acquisition of imagery, subject, of course, to its fixed operating parameters (such as its orbit and altitude).

3. USING REMOTE SATELLITE SYSTEMS TO ENFORCE ENVIRONMENTAL REGULATIONS: ECONOMIC CONSIDERATIONS

3.1 Introduction

A variety of considerations may affect policies regarding what environmental practices we should regulate, where to place the effort we put into enforcing those regulations, and how much we should penalize or punish the violators we detect. Among those considerations are matters of environmental ethics, constitutional law, and equity issues associated with balancing the severity of the punishment with the consequences of the crime. While we acknowledge the importance of these considerations, the criteria we use here to evaluate the specific issue of how RSS technology could or should affect the design and enforcement of environmental regulation is primarily *economic*. As we apply it here, the economic perspective embodies a number of principles:

- The purpose of environmental regulation is to reduce the level of pollution or ecosystem degradation to the point where the benefits of any *additional* environmental improvements just equals the *additional* costs, in lost production or extra abatement, from achieving those improvements.
- The purpose of detecting and punishing those who violate such regulations is to lead potential polluters to take the costs of environmental degradation into account in making their production and abatement decisions.
- Achieving the benefits of enforcing environmental regulations itself involves a variety of costs associated with identifying and measuring potential violations, the accuracy of those measurements, the resolution of disputes regarding liability, and the imposition of specific punishments.

Our objective here is to review the underlying economic analyses of environmental protection and regulatory enforcement, to indicate what factors are most important in deciding how RSS can best achieve the goals of environmental protection and pollution management. In doing so, we believe that an important consideration in achieving these goals is that we find the least costly means of meeting environmental policy targets, and that the benefits of enforcing regulation exceed those minimized costs.

3.2 Economic Fundamentals of Environmental Enforcement

3.2.1 Taxing externalities

The economic grounds for environmental protection began in earnest with A. C. Pigou's *The Economics of Welfare*, originally published in 1920. With that work, Pigou popularized into economics the idea that the costs and benefits of economic activity to the buyers and sellers in markets may diverge from the costs and benefits reaped overall. This divergence comes about, according to Pigou, because

> payment cannot be exacted from the benefited parties or compensation enforced on behalf of the injured parties.[16]

The quintessential cause of this divergence is "the disposal of residuals resulting from the consumption and production process," i.e., environmental pollution in its various guises.[17]

The divergent effects on those "benefited" or "injured" parties have come to be known in economics as "external" benefits and costs or "externalities." The externality-related divergence, in common parlance, is characterized as one between "private" benefits and costs and "social" benefits and costs. The primary policy recommendation regarding externalities that has been inherited from Pigou has been the so-called Pigovian tax:

> It is, however, possible for the State, if it so chooses, to remove the divergence [between private and social costs and benefits] in any field by "extraordinary encouragements" or "extraordinary restraints" upon investments in that field. The most obvious forms which these encouragements and restraints may assume are, of course, bounties and taxes.[18]

The tax forces a polluter to treat the costs imposed by its pollution in the same way it would treat other production costs. Just as, say, a paper mill should pay for the labor it employs and the trees it uses, so too should it pay for the harmful health and amenity reductions it imposes on those downstream and downwind of the mill.

Daniel Spulber offers an observation on pollution penalties that is of particular import here. The Pigovian analysis applies to taxes and liability based upon the damage caused by pollution. Since the pollution is associated with the production of some good or service, these considerations have persuaded some that a tax on the offending output would be appropriate. However, taxing output rather than pollution is appropriate only if pollution is a fixed function of output, regardless of the technology chosen to produce that output.[19] If not, an output tax will control pollution only by raising prices and reducing output, but it will not provide firms

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[16] A. C. Pigou, *The Economics of Welfare* (London: Macmillan, 1932): 183.

[17] R. Ayres and A. Kneese, "Production, Consumption, and Externalities," *American Economic Review* 59 (1969): 282-97, reprinted in W. Oates (ed.), *The Economics of the Environment* (Brookfield, VT: Edward Elgar, 1992): 3-18, at 3.

[18] Pigou, *supra* n. 16 at 192.

[19] D. Spulber, "Effluent Regulation and Long Run Optimality," *Journal of Environmental Economics and Management* 12 (1985): 103-116, reprinted in Oates, *supra* n. 17 at 37-50, esp. 45.

One special case of this proposition would be when there is only one technology available to produce a given level of output, e.g., "fixed proportions" production, where there is no possibility of substituting less polluting production methods or inputs for those which pollute more. In such cases, abatement by means other than reducing output is impossible, by definition.

with an incentive to invest in any pollution abatement.[20] Of course, if emissions are not observable but output is, an output tax becomes relatively inviting, despite this inefficiency.

3.2.2 Transaction costs and liability rules

There has been considerable evolution of the proper interpretation of the optimal tax which a polluter takes into account. The most important step in that evolution was Ronald Coase's "The Problem of Social Cost." This work, which would win Professor Coase the Nobel Prize in 1993, led to the following central ideas affecting the design of regulatory policies for externalities:

- From a cost-benefit perspective, an externality is not something that injurers do to victims, but is inherently reciprocal. Reducing costs of pollution usually means that others have to pay the costs of abatement or bear the losses from reduced supplies of goods whose production makes for a dirtier environment.
- There would be no "problem of social cost," i.e., no externalities, if those who bear the costs of an activity (e.g., pollution) can negotiate an agreement with those who undertake that activity (e.g., polluters). In a world without what have come to be known as "transaction costs," outcomes that maximize net benefits would be reached regardless of whether the polluter bore any legal liability for the pollution. Imposition of taxes would distort or subvert these negotiations, leading to a less efficient outcome.
- When bargaining costs are too high to allow these outcome, however, it need not imply that we ought to impose Pigovian taxes on the polluter. Suppose those potentially harmed by pollution know that the polluter would abate pollution rather than be taxed for damages. Then, they might take actions that lead to excessive abatement, e.g., by building too many homes too close to the polluter. Subsequent refinements of the Pigovian tax have led to the understanding that the tax should be *fixed* at a level based on the size of the externality when the polluter and the potentially injured parties (PIPs) act efficiently.[21] Fixing the tax removes any strategic incentive on the part of PIPs to exploit the situation.
- Similar considerations imply that the case for imposing a tax on polluters does not imply that one necessarily ought to make them liable to compensate victims for damages. As with taxes, policy to compensate victims can lead to excessive willingness to become a potential victim. In particular, full compensation would lead PIPs to make no effort to mitigate pollution damages. Coase points out that

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[20] In a competitive market, an output tax reduces the number of firms in the market, but each firm pollutes as much as it would were there no tax at all. D. Spulber, *Regulation and Markets* (Cambridge, MA: MIT Press, 1989): 366.

[21] The standard reference on these taxes is W. Baumol and W. Oates, *The Theory of Environmental Policy* (Cambridge: Cambridge University Press, 1988): 42–47.

the common law of "nuisance" embodies a desirable flexibility, where courts can impose liability if and only if the external costs brought about by pollution exceed the costs of doing something about it.[22]

- Coase ends his article with the warning that treating externalities as deficiencies between *laissez faire* and a theoretical ideal will lead to undue optimism regarding how well regulation in practice can make amends.

Coase's analysis has been property influential in getting economists to recognize the reciprocal nature of social costs, the subtle effects of taxes, liability rules and compensation, the failure of actual regulation to live up to theoretical ideals, and, most notably, the possibility of eliminating externalities through private transactions. However, in most of the contexts where we see environmental regulation at the state or national level, the ability of private parties to resolve the problems of social cost are attenuated by very high transaction costs. In a typical setting, there are a large number of potentially injured parties, with different preferences for avoiding pollution. High transaction costs will lead this large group of PIPs to fail to negotiate an agreement with each other regarding how much to charge polluters--or how much to pay them not to pollute. The implication is that public policies to mitigate environmental externalities--and the need to monitor compliance with those policies--will continue to merit consideration.

3.2.3 Quantity-based approaches

Emissions taxes may work relatively well when two conditions are met. The first is that regulators can get a good estimate of how much those harmed by pollution would be willing to pay to reduce it. If people would be willing to pay $100 to remove a ton of pollution, but difficulty in measurement leads the regulator to set a tax at $50 per ton, there will still be too much pollution emitted. Measurement error leading to a tax of $200 per ton would impose inefficient costs on society in terms of excessive abatement effort or inordinate reductions in output.

Martin Weitzman's analysis of pollution regulation brings out a second more subtle but equally important condition--that this willingness to pay to reduce pollution is relatively invariant over the likely range of pollution that we might observe.[23] Suppose that the amount of pollution is uncertain, say, because demand for the good whose production leads to pollution is difficult to predict. If so, the effect of a pollution tax will on the total amount of pollution actually produced will also be difficult to predict. If those harmed by pollution would be

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[22] R. Coase, "The Problem of Social Cost," *Journal of Law and Economics* 3 (1960): 1-40, esp. 38. Subsequent analyses of liability law also show that when the victim's level of care affects damages, a strict liability rule will lead to inefficient outcomes, because the victim will have no incentive to take care. W. Landes and R. Posner, *The Economics of Tort Law* (Cambridge, MA: Harvard University Press, 1987): 62-63.

[23] M. Weitzman, "Prices vs. Quantities," *Review of Economics Studies* 41 (1974): 477-91, reprinted in Oates, *supra* n. 17 at 117-31.

willing to pay the same fee to get rid of an additional ton of it, more or less without regard to how much total pollution there is, the optimal emissions tax is independent of this demand variability. The unpredictability of the total amount of pollution will not be of much consequence.

Suppose, alternatively, that the total amount of pollution is crucial. For example, suppose that up to some level of emissions *E*, an additional ton does not matter very much, but beyond *E*, the harm done by each additional ton is very large, exceeding the marginal cost of abatement. If low demand for the good would lead to emissions below *E*, the optimal emissions tax would be very low, but if demand were to be high, leading to emissions above *E*, the optimal tax could be very large. A tax appropriate in high demand periods would lead to excessive abatement and output reductions in low demand periods, and a tax appropriate in low demand periods would lead to excessive pollution-related damages in high demand periods.

In such cases, it could be better to set an overall quantity standard at *E*, rather than to use a tax, letting industry incur whatever expense is necessary to meet that goal. If demand is low, the expense will be minimal; if demand is high, the expense may be significant, yet still below the harm done by exceeding the standard. As exemplified by EPA's marketable SO_2 emissions trading program, there are added efficiencies that one could achieve by distributing the rights to emit a given level of pollutants to the potential polluters, and then letting them buy and sell rights among themselves.[24] The prime advantage is that trading permits gives firms an incentive to implement least-cost methods of eliminating pollution, enabling them to profit by reducing pollution and selling permits to pollute to other firms.[25]

3.2.4 Command-and-control

It would leave a wrong impression to suggest, implicitly, that environmental regulation has typically followed these insights. In particular, regulators have tended to favor "command-and-control" (CAC) methods of reducing pollution. Under CAC, a regulator tells a polluter what specific technology to use to control emissions, e.g., ordering automobile companies to install catalytic converters on cars to reduce the amount of carbon monoxide in

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[24] D. Pearce and R. K. Turner, *Economics of Natural Resources and the Environment* (Baltimore: Johns Hopkins University Press, 1990): 110-15. A good description of EPA's SO_2 emissions trading program is in J. Quarles and W. Lewis, *The New Clean Air Act* (Washington: Morgan, Lewis, and Bockius, 1990): 39-44.

[25] A possible political advantage of permits over taxes is that the government can freely distribute permits to polluting firms, avoiding the wealth transfers that typically accompany taxes. The government could raise revenues, however, by selling permits rather than giving them away.

A potential counter to this advantage in the EPA SO_2 program is that the firms subject to it are electric power plants, most of which are operated by utilities subject to state rate regulation. If state regulators would force utilities to pass any profits from sales of emission permits to electricity customers in the form of rate reductions, they would reduce the incentive for utilities to adopt low cost abatement methods. Burtraw finds that utilities have had a substantial to reduce their own costs of staying under their allotted SO_2 level, but have not engaged in trading among themselves that might further reduce costs industry-wide. D. Burtraw, "Cost Savings *sans* Allowance Trades? Evaluating the SO_2 Emissions Trading Program To Date," Resources for the Future Discussion Paper 95-30 (1995).

their exhaust. Unlike tax-based or quantity-based policies, CAC regulation does not allow firms to implement different, potentially less expensive means for reducing emissions, discouraging the development of new abatement technologies that would make environmental protection even more attractive and effective.

The question "Why CAC?" is directly relevant to our technology assessment. One reason we might see CAC regulation, rather than the ostensibly more efficient tax-based and quantity-based methods, could be that the suppliers of CAC technology are particularly effective at persuading the government to adopt their technologies. A second reason may be that if everyone in an industry knows that the others must use the same CAC-mandated technology, there is less reason to fear that a competitor might gain an advantage by discovering a lower cost means of abatement.

For our purposes it is important to note that CAC regulation offers one considerable advantage--the potential for lower monitoring costs. It is usually easier to tell whether a potential polluter is implementing a specified technology than it is to measure how much that polluter is emitting into the environment. It may also easier for the public to tell if the regulators are doing their job if regulators can be evaluated by the level of implementation of a particular technology for pollution control then by the quantity of pollutants emitted. Of course, mere installation of a pollution abatement device does not imply that it is being used properly, effectively, and consistently with the environmental program goals. However, a regulator's ability to implement more efficient tax-based or quantity-based methods may very much depend on the whether technological advances in monitoring polluters take away CAC's comparative advantage in the choice among environmental policies.

3.2.5 Lessons

For evaluating the contributions RSS technology might make in environmental regulation and enforcement, the central lessons from the basic economics of externalities are fourfold:

- From Pigou, the rationale for environmental policy requires that we have good information regarding the damages that emissions may cause.
- Spulber's analysis brings out the point that ideal policies should be designed around emissions rather than output.
- From Coase, one should investigate how observation technologies may help private parties enforce agreements to reduce emissions, and perhaps reduce transaction costs to the point where private bargaining might substitute for public policy.[26]

[26] Observation technologies are also crucial in enforcing agreements among governments to control emissions. For a discussion of the implications of RSS for both the design of international environmental treaties and potential threats to national sovereignty, see M. Macauley, "Collective Goods and National Sovereignty: Conflicting Values in Global Information Acquisition," *Proceedings of the Conference on Space Monitoring of Global Change* (San Diego: University of California Institute on Global Conflict and Cooperation, 1992): 31–47.

- Weitzman's model has improved our understanding of when implementing quantity-based methods of regulating, such as those in the EPA SO_2 emissions trading program, can improve on tax-based means of pollution control.
- Technologies that can reduce the cost and improve the precision of observing emissions will make both tax-based and quantity-based environmental regulation more effective, and reduce the need to rely on theoretically less efficient command-and-control methods.

3.3 Environmental Regulation: The Law Enforcement Model

3.3.1 The Becker model: Foundations of the economics of enforcement

One might view the essential aspects of the Pigovian and Coasian approaches to environmental externalities as lying on opposite ends of a spectrum. In the Coasian world, resolving externalities is left to the specific parties. They might deal with environmental externalities either through private bargaining or via common law courts that would decide whether the "nuisance" harm from the pollution is sufficiently severe to warrant holding a polluter liable. The Pigovian approach begins with the utmost generality--find emissions, and tax them.

Both positions have their drawbacks. The Coasian bargain depends upon bargaining costs being relatively small. A typical example when bargaining or transaction costs are high are when there are large numbers of persons affected by the acts of a large number of polluters. As the number of parties who need to agree grows, the difficulty in securing an agreement also typically grows.[27] "Large number" problems are also likely to deter persons from attempting to achieve efficient environmental protection through nuisance litigation. Each potential victim will find it in his or her interest to let others carry the burden of enforcing liability rules and securing favorable court decisions, creating a "free rider" problem that could lead to no private enforcement at all. The future precedential value of such actions also ensures that those who litigate these cases will not capture the full benefit of their private enforcement efforts.

These considerations argue for turning environmental regulation to the public sector--recognizing Coase's warning that one needs to look at what the public sector will actually do, rather than what it ideally might do.[28] The generally applicable Pigovian solution of taxing emissions, however, is not without its own set of costs. Adopting a tax solution requires that

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[27] To the extent that these "large numbers" of affected parties fit into a small number of relatively well-organized, homogenous groups, representatives of their organizations may be able to negotiate agreements at relatively low cost through an "environmental dispute resolution" process. G. Binder, "Resolving Environmental Disputes," *Conservation Issues* 6, no. 2 (December 1995): 1-10.

[28] One should recognize that if legal standards or damage award policies unduly favor plaintiffs, or where defendants are insufficiently able to make a credible threat to litigate rather than to avoid litigation costs by settling, incentives to bring nuisance cases can be excessive. However, the possibility that there may be too much private litigation, as well as too little, is also a rationale for leaving enforcement to public agencies that, at least in principle, can take social costs and benefits as well as private costs and benefits of enforcement into account.

the government can measuring marginal environmental damages with sufficient accuracy to determine the efficient tax or output level. A more subtle but perhaps more consequential concern is that monitoring *all* polluters to determine tax payments or compliance with emissions standards, and collecting those payments or distributing permits, are not costless.

Bringing enforcement costs as well as external costs into that analysis leads us to consider environmental regulation as a problem in law enforcement. The leading work on the economics of enforcement, as influential in its field as Pigou's is in the economics of externalities, is by Gary Becker.[29] The most noted result in his analysis is the rather strong one that, if potential violators of laws or regulations dislike uncertainty or are at least indifferent to it, the least-cost method of enforcement involves setting arbitrarily large penalties, while expending only enough effort to detect only an infinitesimally small fraction of violators. Rather than write parking tickets for all who's meters run out, we might save enforcement costs with the same deterrent effect by taking only one violator per year, but giving the violator life in prison. In effect, the few who are caught pay the price for all who fail to comply.[30]

The logic behind Becker's basic result is simple and stark. Taking deterrence as the goal of law enforcement, and punishment as the means for deterrence,[31] the analysis begins with the observation that one thinking about violating a regulation or statute will treat as a

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[29] G. Becker, "Crime and Punishment: An Economic Approach," *Journal of Political Economy* 76 (1968): 169-217, reprinted in G. Stigler (ed.), *Chicago Studies in Political Economy* (Chicago: University of Chicago Press, 1988): 537-92.

[30] To the extent that deterrence is the sole objective of enforcement, this is an acceptable conclusion. It may not be quite so acceptable on ethical grounds. Taking this economic perspective is not to deny that there are legal and ethical limits to how much violators of laws or regulations should be punished. On the legal side, the Eighth Amendment prohibits the imposition of "excessive fines." U.S. CONST. amend. VIII.

From an ethical perspective, imposing on the few who are caught the cost of the violations done by many is to inflict on them a punishment perhaps grossly disproportionate with the harms for which each is specifically responsible. Punishing one person in an extreme fashion, just to economize on enforcement effort while maintaining a given level of deterrence, may be efficient yet, on some ethical accounts, violate the rights of the individual punished. A. Goldman, "The Paradox of Punishment," *Philosophy and Public Affairs* 9 (1979): 42-58. Goldman analogizes punishing a few violators severely, solely to promote overall social well being, to taking hostages in order to force governments to pursue otherwise desirable ends. In short, desirable ends may not justify unethically disproportionate means. If the "end" is not so much promoting social welfare as simply to economize on enforcement effort, Goldman's analogy is all the stronger.

An objection is that violators choose to violate knowing that they may end up paying for all the undetected violations as well. By bearing extreme punishments, the few violators who are detected are in the position of someone who took a gamble and lost, and have no moral justification to avoid facing the consequences. Goldman's response is that the fact that a person could have acted to avoid an unjust act does not make it just to carry out that act if that person chose to act otherwise. The appropriateness of the punishment requires ethical justification independent of whether a violator took the gamble as offered. *Id*., esp. 54–55. In effect, the size of the punishment arises not so much because of what that violator *did*, as from the bad luck of being the one *caught*.

[31] A frequently made objection to economic modeling of the effects of enforcement is that violators do not rationally take costs and benefits into account when deciding whether to obey they law. The force of that objection in the contexts of "crimes of passion" is debatable, but it would not seem to hold much weight in environmental policy contexts, where the potential violators are, for the most part, for-profit businesses.

cost the accompanying *expected* level of punishment. This expectation is the product of two factors: the *size* of the punishment, e.g., level of fine, and the *probability* that one will be punished given that one has committed the violation. For example, if the chance that one will be caught is .5 (or 50%), and the fine if caught is $20,000, then the expected level of punishment is .5 times $20,000 or $10,000. It is this $10,000 that the potential violator will weigh against the other net benefits to him or her of a violation.[32] If this $10,000 exceeds these other net benefits, the potential violator will be deterred.

To this observation, Becker adds three crucial assumptions: (1) increasing the probability of punishing violators is costly, while (2) increasing the size of the punishment is feasible and (3) without cost. The idea behind the first is fairly clear--increasing the probability of punishing violators means that more labor and resources have to be devoted to detecting violations, identifying and capturing violators, and carrying out legal proceedings against them. That increasing the size of punishment is feasible and not costly is considerably more problematic, and looking at how that assumption fails introduces numerous important qualifications to Becker's basic result (including qualifications Becker made himself). The assumption is most reasonable in the case of fines, where in principle a million dollar fine does not cost society any more to impose than a hundred dollar fine.[33]

If increasing the probability P of punishments is costly while increasing the size S of the fine is feasible and without cost, then for any given *expected* level of punishment PS, one can reduce enforcement-related costs by shrinking P and increasing S sufficiently to keep PS constant. This will allow the enforcement agency to maintain the same level of deterrence (based on PS) while reducing enforcement costs.[34] Since this effect always holds, the most efficient, i.e., least costly, enforcement scheme would be to have P as small as possible while still positive, and to set S sufficiently large to keep PS at the desired level. For environmental violations, this would entail cutting back on inspectors and monitoring equipment and effort, instead using enormous fines applied to a very few violators to achieve deterrence. In effect, those few violators pay the Pigovian tax for everyone.

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[32] Strictly speaking, this equivalence holds for potential violators who are *risk-neutral*, i.e., take only expected values in risky situations into account when making decisions. *Risk-averse* potential violators would, by definition, tend to regard a "low probability/high punishment" scenario as worse than a "high probability/low punishment" scenario, if the two had the same expected value, i.e., probability times punishment value. For example, a risk averse person would be more deterred by a .1 chance of getting a $100,000 fine, than by a .5 chance of getting a $20,000 fine, despite the expected fines in both case being $10,000. A risk-neutral person would be equally deterred by both prospects.

[33] The *transfer* of funds from the punished violator to the government does not in and of itself impose costs. Obviously, the violator loses and the government gains, but those effects balance out. The only remaining costs, the administrative costs of collecting the fine, are fundamentally independent of its size.

[34] The level of deterrence would increase if potential violators were risk averse. See *supra* n. 32.

3.3.2 Why invest in enforcement: Limits on increasing punishment

As already noted, the basic economic theory of enforcement--punish a few severely rather than many moderately--depends most crucially on the controversial assumption that punishment can be increased arbitrarily, and without cost. These assumptions may be reasonable in situations where the optimal penalty involves setting fines within some finite range, but there are a number of reasons why they fail to hold as a rule.

Bankruptcy constraints

From an economic perspective, perhaps the most obvious limitation to a policy of increasing fines and minimizing enforcement is that people or corporations have limits on the size of the fines that they can pay. Simply put, they can pay only up to the point that they can convert the assets that they own into wealth. It does no good to impose a million dollar fine on someone with only $10,000 in assets.

If there is a ceiling S^* on the amount one can extract from a violator, the only way to ensure that a given expected level of punishment E^* is faced by potential violators is to undertake enforcement sufficient to generate a probability P of being punished equal to E^*/S^*. The closer S^* is to E^* in magnitude, the more enforcement effort becomes necessary to prevent violations. If S^* exceeds E^*, even complete enforcement would result in insufficient deterrence.[35]

In the environmental context, this may mean that proportionally more effort has to be devoted to uncovering violations by smaller firms rather than larger ones, as the former are more limited in their vulnerability to fines.[36] In any of these cases, the fact that positive effort has to be devoted to enforcement means that enforcement costs, and efforts to employ new technology become important. Along these lines, it becomes important to consider how monitoring costs may vary according to the location of the source, the chemical and optical properties of the specific pollutant, and the variation in time over how that pollutant is emitted. For example, some monitoring technologies may be the least costly means for measuring emissions in remote areas, while others may be more cost-effective for those close to urban areas.

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[35] A potential way to increase the degree of deterrence obtainable when there is a ceiling on fines is to tell potential violators that if they comply, not only will they avoid paying the fine, but they will be monitored less often. In the notation in the text, the expected gain to a potential violator from compliance is more than PS*. W. Harrington, "Enforcement Leverage When Penalties Are Restricted," in Oates, *supra* n. 17 at 543-67; J. Harford, "Measurement Error and State-Dependent Pollution Control Enforcement," *Journal of Environmental Economics and Management* 21 (1991): 67-81.

[36] Of course, if large firms violate more often than small firms, by virtue of their size, this maximum punishment to expected punishment ratio S/E may be no greater for large firms than for small ones, vitiating the need to direct more enforcement effort at small firms. However, firm size, and vulnerability to punishment, is in part at the firm's discretion. A firm knowing it is polluting might make itself smaller, minimizing the amount it could be fined in the event that its violations are detected.

Punishment costs

Another way to escape the limitations of asset liquidity is to adopt nonmonetary punishments. In the U.S., the most common form of nonmonetary punishment is physical incarceration--prison--for various terms. Other forms include, at the lighter end, community service requirements, and at the other end, capital punishment. The costs of these punishments to the violators include the lost earnings from being imprisoned, future losses resulting from a prison record, the value of other aspects of freedom, the unpleasantness of the prison environment itself, and the social stigma attached to incarceration.

The threat of incarceration, on top of fines, allows one to extend the size of the punishment beyond the limits imposed by monetary wealth ceilings. However, the benefits in increasing the feasible size of punishment by carrying out that threat means that punishment itself is no longer costless. Unlike a fine, where the cost to the violator produces a countervailing benefit to the public at large who receives the fine, incarceration has no beneficiary in that direct sense.[37] In addition, society has to bear the costs of ensuring that the incarcerated remain that way for the length of their sentence, leading to expenses on guards, structural security systems, and the like.

A second form of nonmonetary punishment applicable in business contexts such as environmental enforcement, is the procurement embargo. A firm found in violation of environmental regulations could be barred from bidding on subsequent government contracts. The costs to the firm are the foregone profits and contributions to capital recovery that it would lose if it is unable to bid to supply goods and services to the government. Like incarceration, embargoes are not a costless form of punishment. To the extent the embargoed firm is the least cost provider of government-related services, society loses by substitute less efficient firms as providers. Eliminating a bidder from competitions to provide government services also would generally increases the prices of those services to the government, limiting the amount the government would purchase. Moreover, if the increased prices means that the government spends more in total on these services, e.g., where the government's demand for them is independent of price, then the increased drain on the budget means that the government either purchases less of something else or increases taxes, creating losses to the economy in either case.

In situations where society turns to a form of nonmonetary punishment that is costly to carry out, it no longer necessarily pays to substitute more punishment for less enforcement. Whether it does pay to substitute added enforcement for added punishment depends essentially on how sensitively the costs of punishment depend on the severity of the punishment. If the costs of punishment do not go up proportionately with the severity, then it still pays to make punishments more severe, and cut back on enforcement expenses. Only if

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[37] To the extent that incarceration produces specific deterrence, i.e., prevents that particular person from committing more violations, the potential victims may gain something from the incarceration.

the costs go up somewhat more than proportionately with the severity will it pay to increase enforcement.[38]

Even if the cost of punishment rises less than proportionally with severity, there may still be a reason to maintain significant positive levels of enforcement. Essentially, the most severe nonmonetary punishment--death, life in prison--may still have only a finite deterrent value to the potential violator, especially if the chance that the harsh sentence would be carried out is small. Therefore, just as finite wealth requires that enforcement cannot be minimized, so too must the regulator maintain substantial efforts in detecting violators. In the absence of such efforts, even harsh punishments may not lead potential violators to take the social cost of their violations into account.

One might argue that the costs of punishment for pollution could be irrelevant, in that if the punishment is sufficiently severe, it will deter polluters, and thus would rarely if ever have to be applied. However, if punishment costs are high, the threat to carry them out is less credible. If a polluter doubts that a punishment will be applied, because the costs to society as a whole are sufficiently high, having that punishment on the books is an insufficient deterrent. Consequently, punishment costs and limitations on severity matter; even if severe punishments *should* never have to be carried out, potential violators have to believe the enforcers are *committed* to carry them out, otherwise the threat will be empty and no deterrence will be achieved.[39]

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[38] Technically, authorities would minimize the total costs of enforcement by choosing the level of detection so that the marginal cost of detecting an additional offender, divided by the cost of punishing that offender, equals the elasticity of the punishment cost with respect to severity of punishment, minus one.

Mathematically, if V is the number of violators one gets if the expected level of enforcement is E, and P is the fraction of violators who are detected, then PV is the number of violators detected. Let $C(PV)$ be the cost of finding those violators. Define $H(S) = H(E/P)$ as the cost of imposing a sentence of sufficient severity S to ensure that violators perceive the target expected penalty of E, given the probability P of being caught. The total cost of carrying out the sentences is then $PVH(E/P)$, i.e., the number of violators caught times the cost per violator of punishing them with severity S. The total enforcement costs are

$$C(PV) + PVH(E/P),$$

which are minimized when the authorities choose P so that

$$V\frac{dC}{d(PV)} + VH - VS\frac{dH}{dS} = 0.$$

Dividing V and H from all the terms and rearranging yields

$$\frac{dC}{d(PV)} /H = H\,[\frac{S}{H}\frac{dH}{dS} - 1].$$

The expression on the left is the marginal cost of detecting another violator, divided by the cost per violator of carrying out the punishment. The expression on the right is the elasticity of the cost of punishments with respect to severity, minus one.

To get Becker's basic result, assume $H = 0$, regardless of S, the size of the fine. The total cost is now just $C(PV)$, which is minimized by setting $P = 0$, assuming it always costs more to find more violators to punish. For basic models in the environmental economics literature showing that increasing fines and the probability of detection reduce emissions, see J. Harford, "Firm Behavior Under Imperfectly Enforceable Pollution Standards and Taxes," in Oates, *supra* n. 17 at 525–42.

[39] For excellent discussions of the importance of commitment, see T. Schelling, *The Strategy of Conflict* (Cambridge, MA: Harvard University Press, 1980), esp. 21–42, and P. Milgrom and J. Roberts, *Economics, Organization, and Management* (Englewood Cliffs, NJ: Prentice Hall, 1992): 135.

Detection error

The U.S. systems of legal and regulatory processes and appeals are predicated in part on the belief that, certainly in their absence, there is some chance of error, in that violators will go undetected and the innocent will be punished. The source of the error may be overzealous prosecution or the inevitable vagaries associated with gathering evidence and making inferences from it. In addition to the obvious inequity associated with punishing the innocent, this error has two substantial economic consequences. First, the chance that the innocent could be erroneously convicted reduces the marginal punishment that one would expect to incur by violating a law or regulation. Second, increasing chances of error increases the cost of putting oneself in a position where one might be innocent yet punished.

These effects are easily seen by using an example from environmental regulation, and assuming the most extreme form of error—that punishment is assigned randomly. Suppose the regulation is one that limits the emissions of dioxins from medical waste incinerators (MWIs).[40] If a fine for violating were assigned randomly, the first effect is that regulatory enforcement would give no MWI any incentive to limit dioxin emissions. Second, random fines would increase costs to anyone who wanted to start an MWI, discouraging entry into that field. Instead of getting more non-polluting MWIs, a random fine would lead to fewer MWIs, each of which is emitting dioxin.

The possibility of punishing the innocent brings out a number of points regarding detection costs. If some fraction of nonviolators will inevitably be punished, this at least imposed a fixed cost of regulation that could otherwise prevent desirable environmental protections from being enacted. If that fraction of punished *nonviolators* is independent of the number of *violators* who are detected and punished, increasing the level of punishment imposes a cost--deterring additional nonviolators from entering a market.[41] Since increasing punishment imposes additional social costs, the desirability of reducing detection costs increases as well.

However, in addition to creating an interest in reducing the cost of detecting violators, the possibility of erroneous punishment creates an interest in increasing the accuracy of that detection, i.e., in reducing the erroneous detection of nonviolators.[42] If nonviolators are less likely to be punished, all else equal, then a given level of effort put into detecting violators will have a greater effect on deterring violations. Moreover, reducing the number of nonviolators erroneously punished reduces the social cost of increasing the level of

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[40] Environmental Protection Agency, "Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Medical Waste Incinerators; Proposed Rule," *Federal Register* (February 27, 1995): 10653. [located at EPA's Gopher Site].

[41] More generally (and technically), one could say that the effect holds if the fraction of nonviolators detected, divided by the fraction of violators detected, is not a constant number independent of the fraction of violators detected.

[42] Equivalently, one could rephrase this as an interest in reducing the cost of preventing erroneous detections.

punishment.[43] Both of these effects allow the authorities to economize on enforcement and increase the role of fines and punishments in providing effective deterrence.

Concealment by the violators

Violators of environmental laws and regulations are not likely to wait passively to see if they will face punishment for their violations. They are likely to engage in activities to reduce the chances that the will be caught, e.g., surreptitious dumping of hazardous wastes. The possibility that violators could act to conceal violations has a number of implications for the relationship between detection efforts and fines. It also leads us to consider the advantages of enforcement tools that might make it more difficult to conceal violations.

It is useful to consider two cases.

Case 1: Successful concealment: Suppose that we are in a range where the probability of detection and costs of concealment are sufficiently small, and the fine sufficiently large, so that the violator can perfectly conceal the violation. It might seem that there would be no point in spending money to improve the enforcer's ability to detect violations and to make concealment more difficult for the violator. However, this is not entirely the case. Even if concealment is perfect, it costs the violator something to achieve it. That cost itself will deter violations, in that even if violators will never pay a fine, they will

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[43] To model these effects, let P be the probability of detecting violators, and Q be the probability of erroneously "detecting" nonviolators. We can think of P as the detection costs and Q as an indicator of (in)accuracy. Let $C(P, Q)$ be the cost of achieving this degree of accurate detection, where C increases with P and decreases with Q--it is more costly to detect more violators and to avoid wrongly detecting more nonviolators.

As before, let E be the target level of expected deterrence necessary to achieve the desired level of deterrence of violators. Note that if there is a probability Q that one would be detected if one doesn't violate, the added chance of being caught if one violates is $P - Q$. Therefore, to achieve E, we need to set the size of the punishment S such that $[P - Q]S = E$.

The number of nonviolators N is determined by (among other things) QS, the expected punishment a nonviolator faces. The greater is QS, the smaller is N. Let $H(N(QS))$ be the social cost associated with the number of nonviolators, where H rises as N falls. If we fix E, to set the desired rate of deterrence of violations, the total cost of enforcement is

$$C(P, Q) + H(N(QS) = C(P, Q) + H(N(QE/[P-Q]).$$

Choosing P and Q to minimize this cost gives

$$\frac{C}{P} - \frac{H'N'QE}{[P-Q]^2} = 0, \text{ and}$$

$$\frac{C}{Q} + \frac{H'N'PE}{[P-Q]^2} = 0.$$

where H' and N' are the derivatives of H and N, and both H' and N' are negative.

From the second equation, we see that if accuracy increases, then ?C/?Q is closer to zero, reducing the savings from increasing Q, making it more attractive to reduce Q. From the first equation, if Q is smaller, all else equal, the less costly is it to increase the level of punishment, making it is less costly to reduce the level of enforcement. Moreover, the greater is the difference between P and Q, the larger is the denominator in the second term in both of these equations, further reducing the need to invest in greater enforcement. However, if the optimal Q is positive, because preventing error is too costly, then there is a marginal cost of punishment indicated by the second term in the first of these two equations, which gives authorities an incentive to increase resources devoted to increasing the probability P of detecting violators.

still pay the cost of concealment if they violate. Consequently, the enforcer can reduce the number of violations by increasing the cost of concealment, which it can do by increasing the likelihood that violations would be detected absent concealment, and by making it more costly for violators to conceal their violations.[44]

Case 2: Partial concealment: The analysis comes out somewhat differently if concealment is not perfect, and some violators are detected. The situation becomes closer to the basic Becker model, in that fines and punishments have a deterrent effect. However, in this case, increasing the level of the fine or punishment will, all else equal, increase the amount of effort the violators put into concealing violations.[45] While the violators bear these costs, they are real costs to society as well, in that resources that might be devoted to more productive ends are instead diverted into concealment.[46] Consequently, the enforcers will be interested in the ability to detect violators with accuracy, and also to prevent concealment. In addition, the qualifications given above regarding bankruptcy constraints, alternative punishment costs, and detection error all apply to set limits on the size of the punishment, and the need to consider other policies to deter violations.

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[44] Formally, let *P* be the probability of detection absent concealment, and let *X* be the efforts the enforcer makes to make concealment more expensive. Let $C(P, X)$ be the enforcer's cost of *P* and *X*, and let $G(P, X)$ be the cost to a violator of preventing detection, given *P* and *X*. *V*, the number of violations, thus depends (all else equal) on $G(P, X)$. The aggregate amount spent on concealment is *V*, the number of violations, times *G*, the concealment expense per violation. Finally, let $H(V)$ be the social cost of *V* violations. An enforcer minimizing the social cost of enforcement, violations, and concealment would therefore want choose *P* and *X* to minimize total costs

$$C(P, X) + H(V(G(P, X)) + VG(P, X)$$

implying that

$$\frac{C}{P} + V'[H' + G]\frac{G}{P} + V\frac{G}{P} = 0, \text{ and}$$

$$\frac{C}{X} + V'[H' + G]\frac{G}{X} + V\frac{G}{X} = 0.$$

In the first expression, the first term is the marginal cost to the enforcer of effort to increase detection. The second term is the gains from those efforts, which are a product of the increase in concealment cost (?*G*/?*P*), the reduction in the number of violators per dollar of increased cost (*V*'), and the social cost savings per violator, which are the sum of the social cost of the violation (*H*') plus the reduced expenditures on concealment (*G*). The third expression is a countervailing cost of effort, namely that each violator who remains will spend more on concealment. The second expression mirrors the first, except it applies to effort to make concealment difficult rather than efforts to increase detection.

[45] Using a somewhat more complex model, Heyes shows that polluters will increase concealment efforts in response to regulatory efforts to increase the likelihood of an inspection. This response can be sufficiently great that efforts to increase inspection can actually increase emissions. A. Heyes, "Environmental Enforcement When 'Inspectability' Is Endogenous: A Model With Overshooting Properties," *Environmental and Resource Economics* 4 (1994): 479–94.

[46] If the violators believe that they are already concealing as best as they can, so that increasing fines or punishments would not induce additional concealment activity, then the basic Becker model would apply. if it is otherwise feasible to increase fines arbitrarily and without cost, the enforcer can meet deterrence goals at least cost by increasing fines and cutting back on efforts related to increasing detection and preventing concealment.

Choosing between Case 1 and Case 2: To some extent, enforcers can choose whether the violators will find it worthwhile to seek perfect concealment of violations. If the probability of detection absent concealment or the costs of concealment are sufficiently high, or fines and punishments sufficiently low, violators will not find it worthwhile to attempt to achieve perfect concealment. Accordingly, if the enforcers find that severe punishments are too costly, or if they can, at low cost, detect violations and make concealment difficult, then they are likely to find that Case 2 applies. If, on the other hand, severe punishments are not costly to impose, and that it is hard to detect many violators or to discourage concealment, then the enforcer will find that Case 1 is where the total costs associated with detection, discouraging concealment, tolerating violations, and engendering concealment effort are minimized. It is perhaps surprising that an enforcement agency may justifiably be in a position where it is expending resources on detection and making concealment difficult, yet without catching violators and collecting fines or imposing jail terms.

Concealment by the enforcer

While discussing concealment issues, it is worthwhile to consider whether the enforcement authorities should invest in technologies that hide their enforcement efforts from violators of environmental regulations. The "unmarked" police car in search of speeders is a useful example to keep in mind. That there are advantages to do so is perhaps less obvious than meets the eye. Hiding enforcement efforts is valuable only to the degree that doing so affects violator behavior. An necessary condition for there to be any violator effects is that the violators can--undoubtedly at some cost--change their behavior in response to learning that they are being observed *before the enforcer can detect or measure the degree of their violation*.

Consider the "unmarked car" example. Suppose drivers knew that if they saw a police car, they were caught; it would make no sense to decelerate to the speed limit. Then, the fact of being able to observe the car would be irrelevant to their behavior. They would have to choose a speed based on the likelihood that, without warning, they could get a ticket. Drivers would essentially act *as if* all cars were unmarked, if the they cannot avoid a ticket by reacting to the sight of a marked car by slowing down. To put it another way, being able to detect violators before they can react to observing the enforcer's detection effort is equivalent as a practical matter to being able to observe without detection. There would then be no point in investing in technology to conceal enforcement activity.

The case for concealment is by no means certain even if violators can react. If reaction is possible, then the possibility of concealment creates, in a basic setting, two scenarios for violators. In one, they observe detection and react as if continuing to violate would result in a sure fine. In the other, they observe no detection, and thus act taking into account the chance that they may yet be caught by a hidden enforcement device. The first scenario is driving by a marked police car; the second is driving believing that there might be an unmarked car nearby. Holding detection effort constant, increasing concealment by the enforcer essentially moves violators out of the first scenario and into the second.

The consequences of this "scenario relocation" effect are ambiguous. We generally expect that the level of deterrence when violators *know* they will be caught is no less than when they think they *might* be caught. If so, moving violators from the "know" category to the "might" category may be beneficial only if there is too much deterrence (or too much evasion or concealment) when violators know they will be caught. This might occur if for legal or practical reasons, fines have to be set at the same level for violations detected through either overt or covert means. If so, fines set high to reduce violations among those in the "might" category would lead to excessive deterrence among those in the "know" category. For example, firms might overinvest in abatement technology to avoid very high fines if they know they will be caught otherwise.

The possibility points up a potential gain that may arise due to concealment efforts by the enforcer. If the enforcer adopts a detection technology that violators find more difficult to observe, then they will increase their estimated chance that they will be caught. If fines for those in the "might" category are too low to secure optimal deterrence--because of excessive deterrence of those in the "know" or simply because of the aforementioned limits to and costs of punishment--increasing the violators' estimated chance of detection will mitigate this under-deterrence problem, increasing the net social benefits of the enforcer's efforts to detect and punish violators.

Marginal deterrence

Another factor that may limit the size of the punishment, and certainly raises the enforcer's interest in less costly, more accurate, detection technologies, is what economists call "marginal deterrence."[47] The concept seems to refer to two closely related concepts. The first and most basic, which one could trace back to Pigou in economics, is simply that more severe violations should carry more severe expected punishments. If a potential violator is thinking about whether to commit a more serious or less serious violation, the penalty structure should do more to discourage the former than the latter. One way to do this is to make sure that the less serious violations have less serious punishments. Alternatively, enforcers could achieve marginal deterrence not by increasing punishments for more severe violations, but to put more effort into detecting them.[48] In either case, to the extent that considerations of marginal deterrence put a ceiling on punishment levels or warrant differential detection efforts, enforcers will have a need to consider the costs and accuracy of alternative means of detection, as well as the possibility of concealment.

The second conception of marginal deterrence looks at violators who have been or expect to be detected. If fines or punishments are set at the highest possible level to economize on other enforcement costs, those violators will have no incentive to avoid

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[47] R. Posner, *Economic Analysis of Law* (Boston: Little, Brown, 1992): 226–27.

[48] *Id.* at 226, n. 4.

committing further violations.[49] In the environmental context, an example might be that if a firm expects to get the maximum punishment for dumping one ton of a toxic chemical into a river, they have no motive not to dump another hundred tons into the river. The solution is to limit the amount of punishment for lesser violations, to preserve the marginal incentives necessary to deter subsequent, more serious violations by that violator. Limiting punishments, however, gives enforcers the incentive to put resources into detection, and thus resources into employing technologies that reduce the cost of detection.

Effects of punishment size on propensity to convict

The systems of legal and regulatory enforcement do not impose penalties in a vacuum. Enforcers must meet burdens of proof, based on standards such as "propensity of the evidence" in civil cases or "beyond reasonable doubt" in criminal cases. In practice, these standards are inevitably imprecise and subject to the wills of the persons charged with the responsibility of seeing that they have been satisfied. Citing evidence from psychological researchers, Andreoni points out that those people who bear the burden of seeing that burdens of proof have been met will hold enforcers to a higher standard, the higher are the penalties.[50]

This response to severe punishments will reduce the likelihood that violators will face adverse verdicts. If this reduction in adverse verdict rates is strong enough, increasing penalties might reduce *expected* penalties, thus increasing deterrence. Accordingly, enforcers might find it more effective to set penalties lower than what might be otherwise possible, employing enforcement effort and technologies to increase the probability of detection and create the desired level of deterrence.

3.3.3 Lessons

The economics of enforcement offers some specific suggestion in assessing the worth of new environmental technologies.

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[49] Considerations of maximum punishment become may be particularly noteworthy in criminal contexts. Posner argues that we turn to criminal penalties, rather than civil sanctions, in cases where there are low transaction costs--hence, no externalities--permitting markets and private deals to ensure efficient allocations of goods and services. For example, the reason that theft is a criminal violation, whereas pollution is a civil violation, is just because the thief has an alternative way of deciding whether the stolen good is worth more to him than to the victim. The thief can make the victim an offer to buy the good, which the victim can and will accept if the good is worth more to the thief than to the victim.

In externality contexts, such transactions are, by definition, ruled out, so the courts and regulators take the place of the market by setting fines as surrogate expected penalties equal to the harm from the externality. When exchange is possible, in Posner's theory, the ability to seek efficiency at low cost through the market implies that society can and should make alternative ways of reallocating goods, such as theft, prohibitively expensive. Accordingly, when transaction costs are low, expected penalties for going outside the market can and should be arbitrarily high. When expected penalties are uniformly high, the marginal deterrence problem becomes more significant. See Posner, *supra* n. 47 at 220-23.

[50] J. Andreoni, "Reasonable Doubt and the Optimal Magnitude of Fines: Should the Penalty Fit the Crime?" *RAND Journal of Economics* 22 (1991): 385-95.

- To the extent that deterrence at least cost is the goal of the regulator, the first step is to see whether fines can substitute for enforcement effort, to produce expected penalties sufficient to meet those goals.
- Nevertheless, since bankruptcy constraints, alternative punishment costs, detection error, concealment, marginal deterrence, and effects on propensity to convict all put limits on the size of the fines that can be tied to violations, warranting attention to enforcement effort and, consequently, monitoring costs.
- The relative costs of different monitoring technologies are likely to depend on the location of the source of emissions, their chemical and optical content, and variation over time in how those emissions enter the environment.
- The most direct effect of limits on fines and the costs of alternative forms of punishment—incarceration, embargo—is that enforcers will be interested in reducing what it costs to increase the likelihood that violations will be detected and violators will be punished.
- Economic costs and other values bring up the need to minimize punishment of those who do not violate regulations, making accuracy an important consideration in assessing enforcement technologies.
- Violators may be expected to attempt to conceal violations. Enforcement technologies that increase both likelihood of detection and the costs of concealment are valuable--even if violators are able to prevent regulators from detecting violations.
- Enforcement authorities may themselves wish to invest in concealing their activities, but the gains from those investments are problematic.

3.4 Enforcement Considerations in Environmental Regulation

3.4.1 Specific characteristics of environmental enforcement

One lesson from this survey of the economics of enforcement is that many of the important concerns are likely to be very specific to their legal and topical context. In each policy arena, there will be differences in the legal, political, and economic limits on fines and punishments, the degree of concern with wrongful prosecutions, the likelihood of concealment, and other factors, that influence the set of enforcement practices. Evaluators of emissions detection technologies need to recognize the characteristics of the enforcement system that have evolved in the environmental context. A recent list offered by Clifford Russell included the following:[51]

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[51] C. Russell, "Monitoring and Enforcement," in P. Portney, *Public Policies for Environmental Protection* (Washington: Resources for the Future, 1990): 243-74, esp. 248-53.

- Heavy reliance on self-reporting by pollution sources, with infrequent auditing, usually through preannounced site visits, to verify those reports.
- Infrequent use of these self-reports, and often only after extensive delay, by state and federal agencies in initiating enforcement actions.
- Insignificant fines and penalties; sources found to be in violation typically are only ordered to bring emissions into compliance with the regulations.
- Growing reliance on third-party enforcement, through civil litigation, often using source self-reports, which are public.

Since Russell's study of environmental monitoring and enforcement, some of these characteristics may have changed, particularly involving the specter of significant punishments at the federal level. The 1990 Clean Air Act Amendments give the Administrator of EPA authority to set fines of up to $200,000 for all violations, and make "knowing" violations felonies with fines of up to $500,000 per day for corporations, and $250,000 per day and up to five years in prison for individuals. Field agents can write "tickets" with up to $5,000 fines, for violations they observe. "Knowing endangerment" of persons can lead to jail terms of up to fifteen years and corporate fines of up to $1 million per day.[52]

Nevertheless, many of the features mentioned by Russell continue to characterize the environmental enforcement setting. In addition, other research and policy developments have identified additional factors affecting the enforcement of environmental regulations and laws. We review below those factors that are most important for assessing the relative merits of different technologies for monitoring environmental practices subject to legal and regulatory stricture.

3.4.2 Important environmental enforcement characteristics and their implications

Third-party enforcement

If one takes it as reasonable to view the enforcement of crime from the standpoint of economics and cost/benefit comparisons, it should not be surprising to find that other policy perspectives associated with that frame of reference would be suggested. One such theme is privatization. Becker and Stigler[53] noted in 1974 that a great deal of enforcement is already undertaken by private parties, e.g., empowering victims of price-fixing or libel to sue and extract payments from violators of those laws. Even if victims are not the prosecutors, they

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[52] Quarles and Lewis, *supra* n. 24 at 53–56. The business community seems to be reacting to the pressure of stricter enforcement. At a recent conference on hazardous wastes, Kenneth Peterson, CEO of Columbia Aluminum, said, "Things happen, and to be faced with jail time doesn't create a good relationship." "Civil Enforcement Fails to Address Causes of Noncompliance, Conference Told," *Environmental Reporter* (Dec. 15, 1995): 1402.

[53] G. Becker and G. Stigler, "Law Enforcement, Malfeasance, and Compensation of Enforcers," *Journal of Legal Studies* 3 (1974): 1–18, reprinted in Stigler, *supra* n. 29 at 593–611.

may still provide detection effort that substitutes for those of the government, e.g., by facilitating means for victims to report violators to authorities.

Becker and Stigler go on to suggest that privatization could be taken further, by encouraging non-governmental entities other than victims--either for-profit agencies or non-profit interest groups--to undertake enforcement. Rather than undertake the enforcement itself, the government could offer a reward or "bounty" to those who find violators. Essentially, the public could rely on competition in enforcement services to provide the same quantitative and qualitative gains that it achieves by relying on competition in other circumstances--reducing costs and encouraging development of more efficient means for detecting violators.[54]

Enforcement of environmental regulations is showing increasing reliance on third-party enforcement. Current Federal environmental law grants citizens the right to sue those they allege to have violated environmental emissions or permitting statutes, where other governmental authorities have not begun similar actions.[55] Rights to sue under common tort law are also preserved.[56] States and other governmental jurisdictions are allowed to institute and enforce environmental standards more strict than those of the federal government.[57] Technologies that permit third-parties to monitor environmental regulations may be able to help environmental authorities improve compliance and reduce not just their own enforcement costs, but the costs to all able to secure compliance.[58]

Monitoring the enforcers

An additional consideration closely related to third-party enforcement involves monitoring public enforcement agents themselves. To a considerable extent, effective enforcement of laws and regulations in any context depends on the efforts of enforcers, particularly those in the field. Sometimes enforcement can be subverted by a lack of

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[54] Becker and Stigler also argue that paying for enforcement based on success, rather than hiring enforcers on a full-time salary, is likely to increase the effort by enforcers to prosecute violations. A counterargument is that public enforcement may be more aggressive, since the costs of that enforcement are shifted to taxpayers and targets rather borne directly by the enforcers.

[55] 42 U.S.C. 7604 (1994): (a)–(b), (f).

[56] *Id*. at (e). Our understanding of the statute is that aggrieved private parties can obtain damages only though civil action under common law. Private parties who sue under the environmental statutes can obtain orders for injunctive relief and recover litigation costs. *Id*. at (a)(3), (d)

[57] 42 U.S.C. 7416 (1994).

[58] See, for example, A. Florini, "Technologies for Verifying Compliance with Environmental Standards," 1 December 1995 (mimeo): 5–6.

Making data available to third parties may have important implications for privacy, competition, and the stability of cooperative agreements as well. T. Brennan and M. Macauley, "Remote Sensing Satellites and Privacy: A Framework for Policy Assessment," *Journal of Law, Computers, and Artificial Intelligence* 4 (1995): 233-48.

diligence; other times, corruption could prevent the achievement of the goals of the regulations and laws.[59]

In a wide variety of situations, effort by "agents" is difficult to monitor by the "principals" who employ them. So-called "principal-agent" problems can plague a variety of situations, from car repair to corporate management. To try to align the incentives of principals and agents, a variety of compensation schemes have been devised, e.g., paying real estate agents on commission, or limiting outside activities of employees, to induce more effort on the principal's behalf.[60] Becker and Stigler have proposed that one could reward enforcers on the basis of successful enforcement actions, or pay them higher-than-market salaries that they would lose if malfeasance were detected.[61]

The need for these alternative compensation schemes would fall if the enforcers' supervisors and the public at large could get a reliable measure of how much effort enforcers bring to bear. An imperfect but still useful measure would be emissions themselves.[62] Consequently, technologies that can make emissions data available to supervisors within the enforcement agencies and to the public at large may be of considerable use in improving the effectiveness of environmental regulation.

Self-reporting of violations

A striking feature of environmental enforcement is the degree to which state and federal agencies rely on sources to report the levels of pollution. Self-reporting is not as odd as it may seem; tax compliance in the U.S. relies on it heavily. As the tax example shows, the mechanism for ensuring that reporting is timely and accurate are penalties for delayed or inaccurate reports, supported by occasional audits.

The basic intuition supporting a self-reporting system is discussed by Kaplow and Shavell.[63] Essentially, assume that the penalty violators *expect* to receive if the enforcers have to expend effort to detect them is X, where X is the product of the nominal fine F and the probability P that the violation will be detected ($X = PF$). Suppose the enforcer adopts a policy where if a violator reports a violation, it pays Y, where Y is even just a tiny bit less than X. The

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59 Recall that public enforcers may have too much of an incentive to be aggressive, since they do not directly bear many of the costs of resources devoted to enforcement. See *supra* n. 54.

60 For a review, see J. Hirshleifer and J. Riley, *The Analytics of Uncertainty and Information* (Cambridge: Cambridge University Press, 1992): 295–307. One way to improve the performance of agents is to limit outside activities, e.g., through restrictions on conflicts of interest. T. Brennan, "Exclusive Dealing, Limiting Outside Activity, and Conflict of Interest," *Southern Economic Journal* 56 (1989): 323-35.

61 Becker and Stigler *supra* n. 53 at 598–606.

62 The level of emissions is unlikely to be a perfect measure of enforcement effort. Factors beyond the control of the enforcer, e.g., random variation in the performance of monitoring equipment, resistance from the polluters or demand effects that reduce production in the polluting sectors, are likely to affect measured emissions. In some cases, emissions may fall when enforcement has been slack; in other cases, emissions may not fall a great deal despite diligent efforts.

63 Kaplow and Shavell, *supra* n. 7.

enforcer saves on enforcement costs, since it has to inspect only those who do not report violations. The cost would be that paying *Y* instead of *X* will provide less deterrence, but by setting *Y* very close to (but still less than) *X*, that cost can be made arbitrarily small--in particular, less than the savings from not having to audit those who report. Moreover, if the effective fine *F* imposed on those non-reporting violators who are caught must be large and therefore costly to impose (e.g., imprisonment), setting a smaller, easily paid monetary fine on all who report violations may further reduce overall enforcement costs.[64]

In general, self-reporting and inspections are substitute means by which enforcers learn about what violators may be doing. Because self-reporting is a substitute for inspections, the marginal value of improving the inspection process falls in a self-reporting regime. Accordingly, the value of technologies that reduce inspection costs will be lower under a self-reporting system than under a system with no self-reporting, and will tend to make self-reporting less desirable. For example, the savings from self-reporting come about because the enforcers have to make fewer inspections. With fewer inspections, a reduction in the cost of inspecting is less valuable, all else equal. Malik also finds that improved accuracy is less valuable under a self-reporting system.[65]

A second consideration is that models of self-reporting generally do not take into account the costs on the reporting firms of doing the reporting.[66] The extent of concern in environmental rulemakings with paperwork and other compliance costs suggests that this consideration is not trivial. If the cost of imposing the penalty on those who *report* violations is sufficiently high, and if alternative technologies make the costs of inspection sufficiently low, a system with no self-reporting may become preferable.[67]

However, a crucial component of a self-reporting policy is that the enforcer has to *commit* to inspect those who do not report, even though every violator reports because $Y is

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64 *Id.* at 597-98. Using a somewhat broader model that allows for errors in the regulator's inspections, Malik finds a similar result. Malik, *supra* n. 7, esp. 252.

These findings assume that nonreporting firms would face an expected payment of *X* > *Y*. This may not be so in practice. In a recent D.C. Court of Appeals decision found that a nonreporting firm would face no penalties if EPA did not detect the unreported violation within five years. *Minnesota Mining and Manufacturing v. Browner*, 17 F. 3rd. 1453 (1994), reported in "Companies Have Less Incentive to Report Violations in Wake of 3M Ruling, EPA Says," *Environmental Reporter* (Sept. 23, 1994): 1043.

Self-reporting may also be deterred if the penalty for doing so exceeds *X*, e.g., if the information conveyed in the self-report is used to detect other violations or to facilitate third-party enforcement. "Lines Drawn at Hearing on Self Audits; Industry Representatives Favor Privilege," *Environmental Reporter* (July 29, 1994): 587. This effect will be pronounce if the expected penalty *X* for violations is small, as frequently is the case. See *infra* n. 64–65 and accompanying text.

65 *Id*. at 254.

66 Malik's analysis of the cost of imposing penalties on those who report could be interpreted as a cost associated with reporting violations. *Id.*. Kaplow and Shavell, *supra* n. 7 at 600–01, observe without detailed analysis that administrative costs associated with self-reporting could make it less economical.

67 Malik, *supra* n. 7 at 252.

less than $X. Inspections, therefore, would never detect violators.[68] If the enforcer decides not to bother to inspect, because it believes that all the violators have reported themselves, the expected penalty for an unreported violation is no longer $X but zero. Violators will cease reporting their violations, and there will be no deterrence. Consequently, for a self-enforcement regime to work, the enforcement agency has to continue to spend money to ensure that some finite fraction of nonreporters is inspected. Reduced auditing costs may make credible the authority's commitment to inspect, even if such inspections never turn up violators.

Stored vs. as produced emissions: Stochastic and intentional variation

An important characteristic of many pollutants, particularly those associated with industrial production, is whether they are emitted as produced, or whether they are can be stored in such a way to control the rate at which they are released into the environment.[69] A rough generalization may be that gaseous or atmospheric pollutants are in the first category, while liquid and solid wastes are in the second. The source of variability in the production of pollutants is that they tend to match production runs, which can vary both within the standard work day and also across periods of the day, week, and year, as well as being correlated with variations in demand.[70] If they cannot be stored, the emissions will match these production variations, while if they can be stored, the polluter can reduce this variation by smoothing out emissions.

This distinction can affect monitoring technology in two quite different ways. First, suppose that the enforcer can be reasonably assured that stored emissions are emitted on a relatively constant basis. In that case, it would take relatively few measurements to get an accurate reading of the polluter's emissions. A more variable emissions pattern would require more measurements--continuous measurement, in the limit--to get an equally accurate reading. This would suggest that technologies with low variable cost of additional measurement of the same source are more variable when emissions cannot be stored.

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[68] The Kaplow-Shavell and Malik models essentially assume that parties are either in violation or not. Harford models self-reporting where penalties for under-reporting and violations vary with the magnitude of the violation and the under-reporting. For example, a firm would pay higher fines by reporting more pollution, but if caught under-reporting, it would pay a penalty based on how much it under-reported as well as a higher fine for the total pollution emitted. In such a case, firms may not report all their pollution if the under-reporting penalty is sufficiently low. He also finds that firms will reduce pollution and, usually, increase the level of reporting the more frequently they are audited.

Harford's model does not speak directly to the merits of a self-reporting system relative to other systems. His objective is solely to predict polluter behavior when polluters report total emissions, and he does not model auditing costs or the social benefits of reducing pollution. Harford, *supra*. n. 7.

[69] Russell, Harrington, and Vaughan, *supra* n. 6 at 20. As with virtually all binary "either-or" classifications, it would be more technically more accurate to refer to a continuum of possibilities, depending on how much it would cost to store the pollutant.

These authors also provide a useful, brief survey of the economics of enforcement in environmental contexts. *Id*. at 90-105.

[70] Depending on the pollutant, of course, the external cost of the emissions and, hence, the importance of monitoring and enforcement may vary over time as well.

The potential for concealment leads to a different set of considerations. Emissions that can be stored may be easier to hide and to release into the environment at times when the polluter believes monitoring is less likely. The ability to use a technology which makes concealment through timing less likely can be important, particular for those pollutants that can be stored. For example, one consideration would be whether the technology can be used at equivalent cost regardless of the time of the day, reducing the appeal of, say, dumping stored hazardous wastes during darkness. A second consideration along these lines is predictability. If the polluter knows when the monitoring is going to happen, it can time its emissions of stored pollutants accordingly. A technology that can be deployed randomly by the enforcer may be more useful when emissions can be controlled at the source.

Direct compliance control

In their study of the enforcement of environmental laws and regulations, Russell, Harrington, and Vaughn concluded that in the vast majority of states, the penalties for noncompliance were too small to have any significant deterrent effect.[71] In many cases, the "penalty" for violating an environmental regulation is largely only to stop the violation.[72] In essence, noncompliance is treated as if it were a random event independent of the violator's actions and decisions.

Environmental protection is achieved by having the source restore compliance, at least until the next incident occurs. The authority becomes the environmental systems manager *in absentia* for sources within its jurisdiction. One way to characterize this enforcement policy is that the authorities seek to achieve *specific* deterrence--stopping emissions from a particular source through restoration of compliance--rather than *general* deterrence--stopping emissions from all sources through a threat of significant expected fines or punishments.

To the extent that specific deterrence does nothing to reduce emissions from undetected sources, it will fail to force those sources to take the external social costs they impose into account in their production and abatement decisions. Moreover, when sources are competing with each other to sell products and services, specific deterrence will fail to accomplish even the apparent good of reducing net emissions by the amount a formerly noncompliant firm was emitting above the appropriate standard. If some competitors have higher production costs because authorities impose compliance on them while others do not, the noncompliant firms will typically expand production, capturing a part of the market from the now compliant

[71] Russell, Harrington, and Vaughan *supra* n. 6 at 40-43.

[72] "When violations are detected, the offending source is almost always given the opportunity to return to compliance without any sanction imposed for past violations." *Id.* at 44.

firms.[73] The increased production from the noncompliant firms will increase pollution at excessive levels, replacing at least in part the pollutants the compliant firms used to emit.[74]

3.4.3 Lessons

As with our overview of the general economics of externalities and enforcement, the specific research into problems peculiar to the environmental arena highlights some additional considerations for assessing monitoring technologies.

- Technologies that make data available to third parties can facilitate more efficient enforcement of environmental regulations, consistent with environmental statutes and tort law.
- Methods by which supervisors and the public can better monitor emissions may lead to more effective monitoring of efforts by enforcement agents, which in turn can make improve their performance and reduce the need for unorthodox compensation systems to induce greater effort.
- Enhanced ability to audit compliance and reduce the costs of self-reporting can improve the performance of self-reporting schemes, a ubiquitous and potentially cost-saving means for meeting enforcement goals, particularly by making credible commitments to inspect those who report no violations.
- However, the more widespread is self-reporting, the less valuable are improvements in detection accuracy and reductions in its cost, since self-reporting substitutes for inspections and monitoring.
- Reductions in the cost of repeated measurements can improve accuracy when emissions are subject to random variation from fluctuations in environmental, production, and market factors.
- Emissions that can be stored may be easier to conceal, thereby increasing the value of technologies which can be deployed at various times, over schedules that polluters cannot easily predict.
- The ubiquity of specific compliance rather than general deterrence in the environmental enforcement system increases the importance of ensuring that all sources that compete with each other in product markets are treated equally.

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[73] Bob Prolman, director for strategic environmental management at Weyerhauser, recently said that unless all competitors comply with environmental policies, the company that does comply will be at a competitive disadvantage. See "Civil Enforcement," *supra* n. 52 at 1402.

[74] It may help to consider the extreme case, where there are two firms serving a market, and the authorities impose compliance costs on just one of them. If those costs are sufficiently high, the firm may leave that market to its sole competitor. There might be fewer emissions, but only because the specific compliance requirements created a monopoly, with higher prices and lower sales in that market.

3.5 Prescriptions for Monitoring Technology

Looking at the economics of environmental externalities, the enforcement of laws and regulations, and special issues that come up when the two intersect in practice, indicates a plethora of factors that we believe are important in assessing the relative merits of environmental monitoring technologies--in particular, how remote sensing satellites are likely to compare to the alternatives in use and being developed. In this section we summarize the lessons learned with respect to their relevance for the following characteristics of RSS technology in its application to environmental monitoring and regulatory enforcement: the quantity and quality of the information supplied by RSS; access to RSS information (say, by regulators, regulatees, third parties); the cost of RSS information compared with alternative sources of information; and strategic effects of RSS concealment (that is, the "concealed" nature of the act of remote sensing from space).

3.5.1 Information (quantity and quality)

- From Pigou, the rationale for environmental policy requires that we have good information regarding the damages that emissions may cause.
- Spulber's analysis brings out the point that ideal policies should be designed around emissions rather than output.
- Weitzman's model has improved our understanding of when implementing quantity-based methods of regulating, such as those in the EPA SO_2 emissions trading program, can improve on tax-based means of pollution control.
- Economic costs and other values bring up the need to minimize punishment of those who do not violate regulations, making accuracy an important consideration in assessing enforcement technologies.

3.5.2 Access (by regulators, regulatees, third parties)

- From Coase, one should investigate how observation technologies may help private parties enforce agreements to reduce emissions, and perhaps reduce transaction costs to the point where private bargaining might substitute for public policy.
- Technologies that make data available to third parties can facilitate more efficient enforcement of environmental regulations, consistent with environmental statutes and tort law.
- Methods by which supervisors and the public can better monitor emissions may lead to more effective monitoring of efforts by enforcement agents, which in turn can make improve their performance and reduce the need for unorthodox compensation systems to induce greater effort.

- Enhanced ability to audit compliance and reduce the costs of self-reporting can improve the performance of self-reporting schemes, a ubiquitous and potentially cost-saving means for meeting enforcement goals, particularly by making credible commitments to inspect those who report no violations.
- However, the more widespread is self-reporting, the less valuable are improvements in detection accuracy and reductions in its cost, since self-reporting substitutes for inspections and monitoring.
- The ubiquity of specific compliance rather than general deterrence in the environmental enforcement system increases the importance of ensuring that all sources that compete with each other in product markets are treated equally.

3.5.3 Cost

- Technologies that can reduce the cost and improve the precision of observing emissions will make both tax-based and quantity-based environmental regulation more effective, and reduce the need to rely on theoretically less efficient command-and-control methods.
- To the extent that deterrence at least cost is the goal of the regulator, the first step is to see whether fines can substitute for enforcement effort, to produce expected penalties sufficient to meet those goals. Nevertheless, bankruptcy constraints, alternative punishment costs, detection error, concealment, marginal deterrence, and effects on propensity to convict all put limits on the size of the fines that can be tied to violations, warranting attention to enforcement effort and, consequently, monitoring costs.
- The relative costs of different monitoring technologies are likely to depend on the location of the source of emissions, their chemical and optical content, and variation over time in how those emissions enter the environment.
- The most direct effect of limits on fines and the costs of alternative forms of punishment--incarceration, embargo--is that enforcers will be interested in reducing what it costs to increase the likelihood that violations will be detected and violators will be punished.
- Reductions in the cost of repeated measurements can improve accuracy when emissions are subject to random variation from fluctuations in environmental, production, and market factors.

3.5.4 Strategic effects from sensor concealment

- Violators may be expected to attempt to conceal violations. Enforcement technologies that increase both likelihood of detection and the costs of concealment are valuable--even if violators are able to prevent regulators from detecting violations.
- Enforcement authorities may themselves wish to invest in concealing their activities, but the gains from those investments are problematic.
- Emissions that can be stored may be easier to conceal, thereby increasing the value of technologies which can be deployed at various times, over schedules that polluters cannot easily predict.

4. IMPLICATIONS OF NEW RSS TECHNOLOGIES FOR ENVIRONMENTAL ENFORCEMENT

4.1 Nature of the Information to Be Supplied

These new RSS technologies offer opportunities to increase and improve the usefulness of remote sensing for enforcing environmental regulation. Higher resolution sensors will offer more information, and in some cases, more accurate and timely information, than existing systems. Their coverage will also enable a synoptic and geographic context generally unmatched by aerial or *in situ* data. The systems will not, however, supply continuous real-time monitoring information, although as future configurations of RSS systems include more spacecraft, permitting denser data collection, some real-time approximations to continuous monitoring may become available.

The types of environmental monitoring--for different media, such as air, water, and so forth, and for different activities, such as land use or water quality monitoring--to which the proposed systems will be best suited varies widely among the systems, given that each differs in its spatial, spectral, and temporal resolution and geographic coverage. As noted, some systems will operate in the spatial domain of one meter or better, others will operate at three meters, and others around five or ten meters.

With respect to spectral resolution, of the future electro-optical commercial systems described above, several will obtain both pan-chromatic (black and white imagery) and multi-spectral imagery. Generally, the higher spatial resolution systems are panchromatic, reflecting a typical tradeoff in the design of the system--high data rates in the spatial domain usually require lower rates in the spectral domain due to limits in the data-carrying capacity of the spacecraft and the data downlinks. For the same reason, the hyperspectral data--potentially most useful for enforcing clean air regulation, for instance--tend to be grosser in their spatial coverage. Radar data are typically panchromatic for the same reason (radar imaging is particularly data intensive). These limits will loosen as more sophisticated capabilities develop for data compression, on-board data processing, and other techniques to rapidly handle large volumes of data.

The systems also differ in their frequency of coverage and geographic coverage. For example, some satellite systems will provide observations of given points on earth as many as fourteen times a day, but others will only make observations every couple of days. Frequency of coverage is related to geographic coverage, in that both are jointly determined by the spacecraft's orbital and operating parameters. Individual companies operating multiple spacecraft plan to coordinate their coverage parameters. For instance, the QuickBird and EarlyBird spacecraft will be in orbit simultaneously; EarlyBird will orbit close to the poles and cross a given location at the equator every sixty hours, while QuickBird will orbit in a higher inclination, frequently revisiting the most densely developed land masses. Taken together, the spacecraft are intended to provide fairly comprehensive coverage. Similarly, radar data obtained during periods of high cloud cover or at night can complement electro-optical data obtained during cloud-free daylight.

As noted, experts agree that it is not yet clear just how effective new RSS will be in all of its potential applications. There is agreement, however, that the suite of proposed systems will be able to supply significant detail about the following types of phenomena and activities:[75]

- Water: watershed elevation, slope and aspect; hydrography; detection and measurement of pollution and sediment plumes; assessment of land use impacts on water quality; water clarity measurement and tracking; measurement of sea level; location and status of remote lakes and streams; point sources of pollution.
- Air: climatic conditions; human and physical geography of surrounding air quality management areas; some detection, identification, and measurement of chemical content of atmosphere (for example, carbon dioxide, sulfur, aerosols, volcanic residue, water vapor); some measurement of airborne particulates; ozone profiling; air clarity measurement; some point sources of pollution.
- Land: land use and land cover (cultivation and other agricultural uses, abandonment, urbanization, urban infrastructure such as utilities and telecommunications siting and routing, monitoring of land use in corridors of rights-of-way, desert encroachment, integrity and area of forest canopy, vegetation species diversification and distribution); precise location of sites; changes in land at a site over time; environmental profiling and planning; geolocation of oil spills, other hazardous releases, and flooding, fire, and other events.
- Wetlands: detection, mapping, and evaluation of extent and ecological health; historic studies.

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[75] Much of this discussion is based on a report jointly authored by the National Aeronautics and Space Administration and the U.S. Environmental Protection Agency, *Perspectives from Afar: How Remote Sensing and Spatial Information Technologies Can Enable the EPA to Measure Progress towards its Environmental Goals*, 25 July 1995.

- Waste: land use and cover in residential and commercial areas, topography, wind patterns, siting parameters, flood plains; pre-impact and post-impact comparisons; damage assessment; optimal siting of clean-up crews and safe disposal locations; detection of old sites.

4.2 Effects of the New Technologies on Environmental Regulatory Enforcement

In this section, we evaluate the particular advantages of high-resolution RSS information for environmental regulatory enforcement. We invoke our conclusions from Section 3 as a framework; thus, we assess the technologies with respect to the quantity and quality of the information they provide, accessibility of the data, the cost of the data, and the implications of RSS as an observation technology that can be concealed from the observed. Table 2 summarizes our discussion.

Table 2. Implications of New RSS Technologies for Enforcing Environmental Regulations

Factors in regulation and enforcement	Is new RSS advantageous?	Implications for enforcement
Information (quantity, quality)		
geographic coverage	++	permits more accurate assessment of damages, including context
synoptic view	++	permits improved targeting of enforcement activity
Accuracy	+	informs choice between quantity- and tax-based control
real-time coverage of some activities	+	helps minimize punishment of nonviolators
continuous monitoring	-	
Data access		
to regulators	++	facilitates private enforcement by regulatees
to regulatees	++	facilitates role of third parties in enforcement
to third parties	++	reduces need for inspections
in real time	+	
Cost		
of difficult-to-access processes/sites	++	likely to be cost effective compared with aerial or *in situ* observation
of nonobtrusive observation	++	permits some repeated measurements
of concealed sensing	++	lowers enforcement costs, boosts deterrence effects
Sensor concealment	++	increases cost of concealment by observed, increases likelihood of detection, improves effectiveness of enforcement

Key: ++ = significant benefit; + = some benefit; - = no particular advantage

4.2.1 Information (quantity and quality)

The view afforded from space, as distinguished from aircraft or *in situ* measurement, is geographically broad in coverage. For this reason, the space systems supply information relevant to one of the "so what" questions of environmental regulation, namely, what is the contextual impact of activities--on the surrounding environment, the public in the area, and so forth. High-resolution systems will provide particularly detailed synoptic information. In addition, as archives of such data are acquired, the data will also offer an historical contextual perspective useful in "benchmarking" before and after changes (for example, when an industry is required to restore an environmental resource to its original status). The "so what" question can also be answered using satellite data in conjunction with other data, such as census data, to see at a glance a potentially affected population, its demographic, housing, and other characteristics, and other information in a spatial dimension.[76]

RSS thus offers to increase the information base with which to enforce regulation. It may do this in several dimensions: by providing more information, more accurate information, and more information over time. While it is not clear the extent to which details of specific emissions in some media (such as air) will be available from space-based sensing, it can provide a context for understanding the damages that may be linked to such emissions (assuming that data are collected about them through other technologies, like *in situ* devices). This information in turn should confer at least three benefits related to environmental enforcement based on our analysis in Section 3: it can assist in more accurately assessing damages; in better targeting enforcement and remediation (say, with respect to specific sites, times, and so forth); and in providing better information for deciding whether to use quantity- or tax-based means of pollution control. In addition, more accurate information in enforcement can minimize punishment of those who do not violate regulations.

4.2.2 Data access

For numerous reasons, space remote sensing information may be more readily available to regulators, regulatees, and third parties than aerial or *in situ* information. Once a spacecraft is in orbit, data can be collected routinely during the operating lifetime of the satellite. The spacecraft data can also be obtained near real time via distribution to ground stations. The proposed commercial RSS systems all expect to use high speed telecommunications links in transmitting data from the spacecraft to the ground, and for customers without ground stations, will use other electronic delivery mechanisms in sending information from ground stations to customers. The Internet, for instance, figures prominently as a data distribution mechanism in the plans of the proposed commercial RSS systems. As contrasted with aircraft or *in situ* inspections, which are generally privately contracted for or conducted by regulators, access to RSS data is expected to be much more

[76] The use of RSS data as a base map is not new, and other data, such as aerial photos, can also be used as the base over which to lay the census data. However, our point is that the new high resolution RSS data are likely to offer an even better base map.

public--open to any party able to pay for the data. In short, all parties are likely to have access to the satellite data through ordinary market mechanisms.[77]

This accessibility of data may be one of the most significant attributes of RSS for enforcement. For example, RSS data availability may facilitate enforcement of Coasian agreements by reducing transactions costs to the point where private bargaining may substitute for public policy. Alternatively, enforcement agents' efforts may also be cost-effectively bolstered, and actions by third parties--citizens' groups, environmental concerns, and others--may also be informed by RSS data.[78]

In addition, regulatees may find that their own use of RSS data can improve their self-reporting efforts. From Section 3, we know that credible self-reporting can substitute for inspections and monitoring. Moreover, if the accessibility of RSS data encourages credible use (since other parties can acquire the data and check its veracity), then RSS may further reduce the need for inspections.

Another implication of accessibility derived in Section 3 is that data availability can increase the opportunity for even-handedness in monitoring and enforcement. The openness of data access can make it easier for all sources that compete with each other in product markets to be treated equally with respect to enforcement. Accessibility *per se* does not, of course, guarantee that RSS data would be used with such even-handedness, but it does improve the means to do so.

4.2.3 Cost

The new systems are likely to be most cost-effective compared with other means of collecting data particularly when information is sought about processes or locales that are difficult to access, require a synoptic view, or require nonobtrusive (such as a pristine habitat) or concealed sensing (such as random, unannounced site inspections). Little data are now available about the cost of the future high resolution data or the prices that commercial suppliers will set, but some examples based on existing pricing structures are illustrative. For instance, the cost of aerial photography is roughly $250 per hour. Mapping one million miles (say, the waterways in Louisiana) would cost on the order of $1,500,000. The cost of space remote sensing for the task would be about $140,000 for the data, processing, and analysis.[79]

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[77] In cases where data costs may be prohibitive (say, for a community group), one might imagine that grants or other price breaks for data might be made available just as they are for other goods and services for public, charitable, and other social benefit.

[78] Ann Florini emphasizes the use of RSS data in improving the role of third party monitoring and enforcement. See Florini, *supra* n. 58. Some observers have questioned whether third parties and others are likely to be able to interpret RSS data. Low- resolution data are difficult to interpret, but higher resolution images are much easier to understand. In addition, there is a growing consulting industry supplying photo-interpretation expertise. The bigger questions may be whether regulators and courts accept RSS data as proof of compliance. See J. L. Roberts, "Admissibility of Digital Image Data and Animations: Courtroom Concerns," *Advanced Imaging*, August 1995: 101-102; Brennan and Macauley *supra* n. 58.

[79] This example is from NASA/U.S. EPA, *supra* n. 75.

This ratio of around a 10:1 cost savings is aligned with other estimates of 5:1 or better for the use of RSS compared with aircraft measurements. In addition, the costs of using RSS have, in general, been declining for several reasons related to technological change. One is the decreasing cost of small spacecraft and launch services; another is declining costs and increasing capability of software (such as geographic information systems) and hardware (such as computers and processing).[80]

Another cost-related factor is that because the space systems indeed have such broad coverage, they collect information, at close to zero marginal cost, about features that may not have been of interest or noticeable at the time of the review, but that may become important at a later date. In contrast, because most information collected by aircraft or *in situ* has a marginal cost greater than zero, seemingly unimportant data may deliberately *not* be collected by these technologies in order to reduce collection costs (for example, the aircraft shortens or re-orients its flight path, recording sensors are turned off, or, in the case of *in situ* monitoring, ground inspectors limit their spot checks).

If the next generation of space remote sensing indeed results in more cost-effective information, then there are several implications for policy. One is that reductions in the cost of repeated measurements can improve accuracy and the likelihood of detection of violations of environmental regulations. Repeated measurements may also facilitate detection when polluting activities are subject to random variation from fluctuations in climatic and other factors, or when emissions can be stored for purposes of eluding detection. A related implication is that lower monitoring costs can facilitate enforcement and in turn, boost any deterrence effects of that enforcement. This approach to deterrence can be an alternative to fines, which, as we noted, are limited in that their size may not be large enough to be feasibly tied to violations (due to bankruptcy constraints, marginal deterrence, propensity to convict, and the other factors we discussed in Section 3.5).

In addition, more cost-effective information may permit greater use of economic incentive-based approaches to regulation (and enforcement) rather than command-and-control approaches, which are theoretically less efficient. Recall that the advantage of CAC regulation is that it can reduce monitoring costs--installation of a smokestack scrubber, for example, is readily observable. To the extent that space based remote sensing provides enforcement information at low cost, it may reduce this advantage of CAC.

4.2.4 Strategic effects from sensor concealment

Space remote sensing technologies have a unique attribute, and that is some ability to observe without the awareness of the observed entity. It is important to note that the orbital parameters of the systems are public knowledge through the licensing process the systems

[80] Another important development is the availability of the global positioning spacecraft system (GPS), a U.S. Department of Defense network that provides precise location and timing signals for all types of space- and ground-based activities. For discussion, see S. Pace and co-authors, *The Global Positioning System* (Washington, DC: RAND Corporation, 1996).

must undertake. It is not inconceivable that anyone could obtain these parameters, calculate when the spacecraft will be passing overhead, and take actions to conceal activity during these times (although it is not clear how much it will cost parties to take such action).[81]

The possible opportunity to conceal the act of observation (assuming the observed party does not take averting action) has several policy-related results. For instance, among three recommendations Russell makes in an analysis of environmental monitoring and enforcement policy, two relate to concealment. He advances the desirability of unannounced and warrantless inspections, arguing that "there should be no anticipation of privacy in the generation and discharge of pollutants."[82] While this recommendation need not require that the observation technology be hidden from view of the observed, RSS offers the opportunity to do this, and to do so cost-effectively. Russell also argues for the desirability of remote sensing methods "that are capable of measuring stack emissions from outside the factory or utility gates."[83] The usefulness of the concealment property of RSS is that it can increase both the likelihood of detection and the costs of concealment by the observed, thus improving the effectiveness of enforcement activities.[84]

5. CONCLUSIONS

Our review of economic models of environmental protection and regulatory enforcement has highlighted several attributes that are particularly likely to benefit from new enforcement technologies such as RSS. These attributes include the quantity and quality of information supplied by the new technologies; the accessibility of the information to regulators, regulatees, and third parties; the cost of the information; and whether the process of information collection can be concealed from the observer. RSS technologies are likely to influence all of these attributes and in general, improve the efficacy of enforcement. We make the following observations in this regard:

- While it is not clear the extent to which emerging RSS technologies will detect specific emissions in some media (such as some types of gas emissions), high resolution data can provide a context for understanding the damages associated with environmental pollution. In turn, this information confers at least three benefits for environmental enforcement: it can assist in more accurately assessing damages; in improved targeting of enforcement and remediation, and in providing information for the decision whether to use quantity- or tax-based means of pollution control. In addition, more accurate information such as that offered by

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81 To be sure, some activities are not readily concealed, but the concealment effort is likely to be largest when the penalties for non-compliance are most egregious.

82 Brennan and Macauley *supra* n. 58.

83 Russell, *supra* n. 51.

84 We are not arguing that the enforcement authorities should necessarily conceal their activities. Recall from Section 3.3.2 that the gains from so doing are problematic.

high resolution RSS may minimize punishment of those who do not violate regulations.

- The accessibility of new RSS data to all parties--regulators, regulatees, and third parties--may facilitate private enforcement as a substitute for public policy by reducing transactions costs. Regulatees may also use RSS data for their own self-reporting efforts, which if credible, can substitute for inspections and monitoring. Credibility of the data may be heightened by its public accessibility. Accessibility also increases the opportunity for even-handedness in monitoring and enforcement, in treating equally all sources that compete with each other in product markets.
- If new RSS data represent a more cost-effective source of information compared with alternative data sources, then repeated measurements might be economically taken using RSS, thereby improving accuracy and the likelihood of detection of violations of environmental regulations. Repeated measurements may also improve detection of polluting activities subject to random fluctuations due to climate or other factors. Lower monitoring costs can also boost any deterrence effects of enforcement by making enforcement easier, and this approach may be an alternative to fines. In addition, more cost-effective information may permit greater use of economic incentive based approaches to regulation (and enforcement) rather than command-and-control approaches, which are theoretically less efficient.
- Finally, the opportunity for RSS to serve as a concealed means of observation can increase both the likelihood of detection and the costs of concealment of activities on the part of the observed entity, thus improving the effectiveness of enforcement actions. We note, however, that the operating parameters of RSS are a matter of public record and therefore make it possible for observed entities to conceal their actions when a spacecraft is expected to be overhead.