Title
Science and Uncertainty in Environmental Regulation: Insights from the Evaluation of California's Smog Check Program

Authors
Bedsworth, Louise Wells
Kastenberg, William E

Publication Date
2003-03-01

Science and Uncertainty in Environmental Regulation: Insights from the Evaluation of California's Smog Check Program

Louise Wells Bedsworth
William E Kastenberg

UCTC
No. 617

The University of California Transportation Center

University of California
Berkeley, CA 94720

The University of California Transportation Center

The University of California Transportation Center (UCTC) is one of ten regional units mandated by Congress and established in Fall 1988 to support research, education, and training in surface transportation. The UC Center serves federal Region IX and is supported by matching grants from the U.S. Department of Transportation, the California Department of Transportation (Caltrans), and the University

Based on the Berkeley Campus, UCTC draws upon existing capabilities and resources of the Institutes of Transportation Studies at Berkeley, Davis, Irvine, and Los Angeles, the Institute of Urban and Regional Development at Berkeley, and several academic departments at the Berkeley, Davis, Irvine, and Los Angeles campuses. Faculty and students on other University of California campuses may participate in Center activities. Researchers at other universities within the region also have opportunities to collaborate with UC faculty on selected studies

UCTC's educational and research programs are focused on strategic planning for improving metropolitan accessibility, with emphasis on the special conditions in Region IX. Particular attention is directed to strategies for using transportation as an instrument of economic development, while also accommodating to the region's persistent expansion and while maintaining and enhancing the quality of life there

The Center distributes reports on its research in working papers monographs, and in reprints of published articles. It also publishes *Access*, a magazine presenting summaries of selected studies. For a list of publications in print, write to the address below

University of California
Transportation Center

108 Naval Architecture Building
Berkeley, California 94720
Tel 510/643-7378
FAX: 510/643-5456

Science and Uncertainty in Environmental Regulation: Insights from the Evaluation of California's Smog Check Program

Louise Wells Bedsworth
Energy and Resources Group
University of California, Berkeley

William E. Kastenberg
Department of Nuclear Engineering
University of California, Berkeley

Reprinted from
Science and Public Policy
Volume 29, No 1, pp 13-24 (2002)

UCTC No. 617

The University of California Transportation Center
University of California at Berkeley

Science and Public Policy, volume 29 number 1, February 2002, pages 13–24, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Environmental regulation

Science and uncertainty in environmental regulation: insights from the evaluation of California's Smog Check program

Louise Wells Bedsworth and William E Kastenberg

Environmental decision making is a complex process confounded by technical uncertainty, political pressure, and societal interests. New calls for environmental decision-making frameworks emphasize the need for an holistic approach that incorporates technical and non-technical expertise, and participation by all interested and affected parties. In this paper, we analyze the evaluation of an environmental regulatory program to characterize the interaction of science and policy and the processing of uncertainty using concepts from science and technology studies. This demonstrates the influence of institutional goals and commitments on the uptake and use of science and the processing of uncertainty in the regulatory process. We discuss the implications of such analyses on the development of new environmental decision-making frameworks.

Louise Wells Bedsworth is in the Energy and Resources Group and William E Kastenberg (corresponding author) is in the Department of Nuclear Engineering, University of California at Berkeley 4103 Etcheverry Hall #1730, Berkeley, CA 94720-1730 USA, Tel +1 510 643 0574, Fax +1 510 643 9685, E-mail kastenbe@nuc berkeley edu

The authors are grateful to David Guston and an anonymous reviewer for helpful comments on earlier drafts of this paper They also thank the numerous participants in the Smog Check II evaluation process who have supported this research Funding for this project was provided by the EPA STAR Graduate Fellowship program and the University of California Dissertation Year Fellowship

RESOLVING COMPLEX environmental regulatory issues requires consideration of the technical, political, and societal implications of a decision Several national studies have recognized this requirement and have suggested integrated or holistic methods for approaching complex environmental decision making Such frameworks include broader societal and political considerations, participation of all interested and affected parties, and maintaining a sound scientific basis (NRC, 1996, Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997)

Existing decision-making paradigms such as cost–benefit analysis or utility theory do not provide conceptual or procedural connections between these considerations Nonetheless, most of the work on integrated decision making to date has centered on constructing methods that rely on decision analytic methods such as multiattribute utility analysis and its variants and derivatives (Keeney and Raiffa, 1976, Merkhofer and Keeney, 1987, Hong and Apostolakis, 1993, Reckhow, 1994, Apostolakis and Pickett, 1998)

In this paper, we explore uncertainty in environmental regulation using methods and theories from science and technology studies (STS) This analysis demonstrates why it is difficult, if not impossible, to represent environmental decisions fully using a utilitarian or cost–benefit methodology We examine a specific case in regulatory environmental decision making, the evaluation of California's motor vehicle inspection and maintenance program, and show how interactions of science and policy and the processing

 0302-3427/02/010013-12 US$08 00

Louise W Bedsworth is a doctoral candidate in the Energy and Resources Group at UC Berkeley Her dissertation analyzes the interaction of science and policy in the design and evaluation of California's Smog Check program

Bill Kastenberg is the Daniel M Tellep Distinguished Professor of Engineering, University of California at Berkeley He teaches courses and supervises research on risk analysis, nuclear reactor safety, environmental conflict resolution and multi-stakeholder decision making, and more recently, on engineering ethics

of uncertainty shape the regulatory discourse through argument formation and debate

Further, we argue that an understanding of the science policy interface and the treatment of uncertainty in the decision-making process provides a strong conceptual and analytical foundation through which environmental decision making can be analyzed and understood While exploratory in nature, this paper aims to demonstrate the power of narrative or descriptive approaches, such as STS, in the study and practice of environmental regulatory decision making

Expertise, uncertainty and decision making

Traditional models of the science policy interaction represent science as a source of objective truth that guides the decision-making process (the 'truth speaks to power' model) This model has served to inform and advocate the application of cost–benefit and utilitarian models to decision making Insights provided by researchers in STS and other fields have demonstrated that this model of the science policy relationship is illusive (see, for example, Majone, 1989, Jasanoff, 1990, Herrick and Jamieson, 1995, Elzinga, 1997, Jager, 1998, Jasanoff and Wynne, 1998) Sheila Jasanoff has shown how scientific knowledge and 'facts' are contingent and constructed, resulting in their deconstruction in the regulatory arena (Jasanoff, 1986, 1987, 1990)

These challenges to the authority and legitimacy of science result in attempts to construct boundaries Boundaries and their associated 'boundary work' are attempts to classify knowledge, information, or even people and groups as legitimate vs illegitimate, scientific vs unscientific, or insider vs outsider (Gieryn, 1983, Jasanoff, 1990) These processes of deconstruction, boundary definition, and boundary maintenance often bring scientific inputs and, especially, uncertainty into the center of regulatory debates and challenges both as the issues of contention and as leveraging tools

Simon Shackley and Brian Wynne have demonstrated how different interpretations of the same technical phenomenon, uncertainty, or fact can serve as a means of communication across these boundaries between different social groups or "worlds" (Shackley and Wynne, 1996) In this role, facts, phenomena, and uncertainties serve as "boundary objects" or "boundary ordering devices" (Gieryn, 1983, 1999)

In addition to its importance at the boundaries between social worlds, uncertainty serves as a powerful means to promote action, inaction, or delay in the regulatory arena (Majone, 1989, Funtowicz and Ravetz, 1990, van Asselt *et al*, 1996) Campbell shows how uncertainty can serve as a locus of debate among experts and as a strategic tool that enables an expert to maintain authority in a given situation (Campbell, 1985) Susan Leigh Star has shown how uncertainty is used to reify the authority of science through the transformation of local uncertainties into globally-accepted certainties that are managed and controlled by science, thereby maintaining its authority (Star, 1985)

In addition to the discussion of its role as a rhetorical and strategic tool, the meaning of the word 'uncertainty' has been discussed and defined by many different researchers Several definitions and classifications of uncertainty exist in the environmental policy literature As Table 1 illustrates, these range from definitions that are primarily technical to those that encompass a broader, constructivist view of scientific information and the decision-making process

The breadth in the definition of uncertainty suggests it is more than a statistical or probabilistic phenomenon Rather, uncertainty extends from data and models into suppositions based on that information, problem definitions, and the design of solutions

Table 1 Uncertainty classification schemes

Researcher	Classes of uncertainty
Morgan and Henrion (1990)	Uncertainty in empirical quantities Uncertainty in model form
Rowe (1994)	Temporal uncertainty Structural uncertainty Metrical uncertainty Translational uncertainty
Shrader-Frechette (1996)	Framing uncertainty Modeling uncertainty Statistical uncertainty Decision-theoretic uncertainty
National Research Council (1996)	Aleatory uncertainty Epistemic uncertainty Indeterminacy[a] Ignorance
Funtowicz and Ravetz (1990, 1992)	Inexactness Unreliability Border with ignorance
Wynne (1992)	Risk Uncertainty Ignorance Indeterminacy[a]

Note [a] There is an important distinction between indeterminacy as defined by NRC and as defined by Wynne NRC states that indeterminacy is uncertainty about which model to use Wynne's definition poses a question that overlays the entire science–policy interaction Does policy direct science or is policy modified to justify science?

The breadth in the definition of uncertainty suggests that it is more than a statistical or probabilistic phenomenon: it extends from data and models into suppositions based on that information, problem definitions, and the design of solutions

The six classifications shown in Table 1 range from those that are predominantly technically based, focusing on data and models (Morgan and Henrion, 1990), through those that address uncertainty in the policy process including communication and problem framing (Rowe, 1994, Shrader-Frechette, 1996), to those that address epistemic limitations to science and the realm of ignorance (Funtowicz and Ravetz, 1990, 1992, Wynne, 1992, NRC, 1996)

Drawing on these definitions of uncertainty and insights into the interaction of science and policy from STS, we examine an environmental regulatory process and the associated uncertainty in detail Our analysis demonstrates why expanded definitions of uncertainty are needed to understand the environmental regulatory process

Further, our analysis of the interjection of science and uncertainty into the regulatory discourse provides an account of how actors in the regulatory decision-making process construct arguments through the presentation and interpretation of scientific information, and the interpretation and emphasis on different types and sources of uncertainty Together, these characteristics of the environmental regulatory process suggest that understanding the process of applying scientific information to environmental regulation is an essential component of understanding the arguments, controversies, and actions in environmental regulation

Case study: Smog Check II evaluation

In this case study, we examine the evaluation of California's enhanced motor vehicle inspection and maintenance (I/M) program, Smog Check II I/M programs require registered vehicle owners to have their vehicles' emissions and their emissions control systems tested on a regular basis We have chosen to examine this program because it contains many elements common to environmental regulatory decision making Metrics of success are uncertain and non-uniform, there is not agreement among the participating and/or interested groups on the appropriate methods of evaluation, and political commitments and public accountability rely on the success of the program

In addition, there are high environmental and economic stakes associated with a successful motor vehicle inspection and maintenance program In California, Smog Check II is responsible for one quarter of the emissions reductions outlined in the State Implementation Plan (SIP) These reductions are needed for the most polluted areas in California if they are to meet the National Ambient Air Quality Standards (NAAQS) [1] If these standards are not met, the state can lose billions of dollars in federal highway funds through sanctions imposed by the United States Environmental Protection Agency (USEPA)

In this paper, we analyze the evaluation of Smog Check II, and characterize the processing of uncertainty Specifically, we focus on how participants and reports present and discuss evaluation methods and results Also we examine what types of uncertainty arise in the evaluation process and how these translate into the regulatory discourse

Background

USEPA states that I/M programs are designed to "ensure that vehicles stay clean in actual consumer use [encourage] proper vehicle maintenance and discourage tampering with emission control devices" (USEPA, 1994, page 1) I/M programs were included in the 1977 Amendments to the Clean Air Act as a way for states to attain the NAAQS, but more prescriptive guidelines were included in the Clean Air Act Amendments of 1990 These required the most polluted of the areas designated non-attainment for the carbon monoxide (CO) or ozone (O_3) NAAQS to implement enhanced inspection and maintenance programs [2] Enhanced I/M programs are designed to measure tailpipe emissions of CO and the precursors of O_3 formation, hydrocarbons (HC) and oxides of nitrogen (NO_x) In addition, the enhanced I/M test as envisioned by USEPA, includes the measurement of evaporative HC emissions

The Clean Air Act Amendments of 1990 and USEPA's final rule envisioned enhanced I/M programs as centralized, test-only programs In a centralized program, vehicles are tested at a station run by a contractor who is responsible for all the testing facilities in the region and that testing is conducted at a facility separate from repair The final rule also included a requirement that all emissions tests are to be conducted using a dynamometer, or a treadmill-like device for cars, and are to use a specific test method called the IM240 [3] Inspections in USEPA's enhanced I/M program also test evaporative emissions from vehicles, not just tailpipe emissions (USEPA, 1992)

Different incarnations of California's Smog Check program have been in place since 1984 The program has undergone a number of changes as a result of technical improvements and regulatory requirements Prior to the 1990 Clean Air Act Amendments, the entire state was subject to Smog Check testing either biennially or on change of ownership of the vehicle, depending on the air quality in each geographic region within the state All testing was performed at privately owned service stations using a two-speed tailpipe test

The Clean Air Act Amendments of 1990 required that the most polluted areas of the state implement enhanced I/M as defined by the USEPA Enhanced I/M was designed to reduce the impact of fraudulent testing, tampering, and cheating on the performance of I/M programs by separating test and repair and to use high-tech testing equipment suited to modern technology vehicles (USEPA, 1995) Currently, there are three different forms of the Smog Check program in place in different geographic regions in California — basic areas, change-of-ownership areas, and enhanced areas [4] Smog Check II testing is only in place in the enhanced areas

The service station industry in California resisted implementing USEPA's enhanced I/M program because of the loss of emissions-testing revenue (repairs could still be performed under a centralized program) and the high cost of the IM240 test equipment Because of these pressures and concerns about consumer convenience, California was reluctant to create a completely centralized program like the one the USEPA required

After the Clean Air Act Amendments of 1990, California entered negotiation with the USEPA and reached an agreement in 1994 to create Smog Check II, the hybrid program currently in place in the state's most serious non-attainment areas This program is an important part of the SIP, the regulatory document the state is required to submit to USEPA showing how and when areas of the state that do not meet the national ambient air quality standards will come into compliance

Smog Check II contains some of the elements of USEPA's prototype enhanced program, but maintains a network of independent stations that perform both test and repair This case study focuses on the evaluation of this hybrid program, which was required after two years of program operation

Evaluation process

The USEPA's final rule on enhanced inspection and maintenance programs requires states to evaluate their I/M programs biennially, beginning two years after the implementation of inspections (USEPA, 1992) In California, the evaluation process is a politically contentious issue for a number of reasons To begin with, the program is not achieving the emission reductions that it is obligated to in the SIP (ARB, 1994, 2000) A failure to meet the SIP requirements affects the state's timeline to meet federal air quality standards, which can, in turn, affect the state's receipt of federal funding for transportation projects Smog Check II has also been a political 'hot' issue in California since the enhanced program was proposed following passage of the 1990 Clean Air Act Amendments, attracting the interest of classic car collectors, service stations, and motorists

Institutionally, Smog Check II evaluation is a complex process as well The Bureau of Automotive Repair (BAR), a division of the California Department of Consumer Affairs is responsible for overseeing the program Table 2 shows the regulatory agencies involved in Smog Check and their responsibilities Both the Air Resources Board (ARB) and the Inspection and Maintenance Review Committee (IMRC) are responsible for evaluating the program

While the purposes of the two evaluations are different (ARB prepares an evaluation to be submitted to the legislature and USEPA to demonstrate SIP compliance, and the IMRC prepares an evaluation to be given to the state legislature) the public presentation of the results highlights important differences between the two organizations These differences exist in the agencies' missions, commitments, and accountability

In addition to the political and institutional challenges, the evaluation process is a technically complex endeavor because of the difficulty both in obtaining data and in selecting an evaluation methodology The variability of the driving cycle, uncertainty in measurement, and the influence of driver behavior combine with other factors to make it very

Table 2 Governmental organizations involved in Smog Check

Group		Programmatic responsibility
Bureau of Automotive Repair (BAR)	-	Division of the State Department of Consumer Protection Implements Smog Check Certifies, trains, and monitors stations and technicians Collects program data Develops specifications for testing equipment and procedures
Air Resources Board (ARB)	-	Division of the California Environmental Protection Agency Prepares State Implementation Plan (SIP) Demonstrates SIP compliance to EPA
Inspection and Maintenance Review Committee (IMRC)	-	Appointed by the governor and the legislature to monitor the performance of Smog Check, evaluate the program, and suggest program improvements Evaluate Smog Check and present results to the legislature Hold (regular) public meetings
Department of Motor Vehicles (DMV)	-	Register vehicles Maintain database of inspection certificates for vehicles Send out Smog Check reminders with registration renewal notices
US Environmental Protection Agency (USEPA)	-	Wrote and designed requirements for enhanced I/M Oversees implementation of the Clean Air Act legislation Oversees state programs and evaluations Approves/rejects SIP

problematic to obtain representative vehicle emissions data

Given the challenges encountered in obtaining representative data, there are often many information gaps that must be filled in the evaluation process When information is lacking, emissions models can be used to fill in data gaps, but the models remain highly uncertain These technical challenges provide a lively basis for regulatory debate, particularly since there is no single, agreed upon method for program evaluation

Evaluation as regulatory science

Given the context and the regulatory motivation for the evaluation, the evaluation process closely resembles regulatory science as defined by Jasanoff (1990, page 80) She defines three main components of regulatory science knowledge production, knowledge synthesis, and prediction (1990, page 77) The Smog Check evaluation process shows evidence of all three knowledge production in the gathering of emissions data, knowledge synthesis in the analysis of this data, and elements of prediction are seen in how this information is brought together and how it is presented as a measure of program effectiveness

Another aspect of the evaluation process that reflects the characteristics of the regulatory science is in the ARB's and the IMRC's use of "boundary work' Jasanoff describes boundary work as a process of identifying who is in and who is out, or in what realm a particular issue lies (1990, page 14) In the presentation of evaluation results, the ARB and the IMRC attempted to maintain a boundary between the 'numbers' and the policy recommendations In IMRC public meetings, the committee chairperson continually expressed a desire to maintain a separation between the "findings of fact",[5] or the evaluation results, and policy recommendations based on these findings At one point the IMRC chairperson said

> " I want to really emphasize — it is important to separate out the empirical results from any recommendations The results simply tell us what do we know, what do we observe Judgements about policy have to take into account such things as — where do we need to be with respect to the federal law They need to take into account considerations about impacts on different universes of citizens in the State of California let us not mingle the two "[6]

Through this boundary construction, the committee attempted to protect the findings from political influences so that they remained legitimate bases for the committee's policy recommendations

In the tight coupling of policy and science in the regulatory science process, uncertainty is often the locus of debate It is used to bolster and support opinions, agendas, and conflicts (Jasanoff, 1990, Funtowicz and Ravetz, 1992, Ozawa, 1996, van Asselt *et al*, 1996, van Asselt and Rotmans, 1996) Uncertainty is amplified or ignored, or sometimes a combination of the two, depending on the motivation of different actors (Wynne, 1987)

In a regulatory decision-making process, uncertainty can be used to advocate precaution in pursuing potentially harmful environmental choices (the Precautionary Principle), to advocate cost-effectiveness, or to delay regulatory action altogether Uncertainty serves as an influential rhetorical and strategic device in environmental regulation and decision making

Uncertainty in the Smog Check II evaluation

Before the completion of either of the evaluations, a member of the IMRC stated in an interview that if their evaluation " shows that [Smog Check] is falling well short of the mark, I think that you will get people simply disputing the data "[7]

Uncertainty in evaluation reports

Several technical uncertainties affect the evaluation process As was acknowledged in almost every interview conducted, the data that is available on I/M program performance is often contradictory, difficult to obtain, and generally scarce In addition, many data sources have been used to challenge the validity of I/M programs by supporting a characterization of vehicle emissions and driver behavior that contradicts the characteristics represented or addressed in current I/M program design and the models that are used to predict their benefits (Lawson, 1993, 1995, Stedman *et al*, 1997, 1998) Given the controversy over data and its use in critiques of I/M programs, data selection and availability is a very important component of the evaluation process

Simply put, data on vehicle emissions are needed for the evaluation of an I/M program to estimate emissions before and after a Smog Check II inspection in order to arrive at an estimate of program benefits Several different sources of data were available in the Smog Check II evaluation First, millions of emissions measurements are collected when vehicles have their scheduled Smog Check II inspection (close to nine million vehicles are tested per year) These data are contained in the Vehicle Identification Database (VID), and are referred to as VID data

Second, roadside inspections have been conducted by BAR on tens of thousands of vehicles that were randomly pulled over In a roadside inspection, emissions are measured using the Smog Check II inspection protocol (roadside data)

Finally, some vehicle measurements are taken using a remote sensing device (RSD) that uses a spectrophotometer to measure emissions in an exhaust plume as a vehicle drives by a specific location

Uncertainties that arise in relation to the data are in measurement, variability, reliability, and the data's ability to represent actual on-road vehicle emissions: each of these needs to be managed in the calculation of program benefits

(Bishop and Stedman, 1996). Such a measurement is taken without stopping the vehicle and without even, necessarily, notifying the driver (RSD data).[8]

A number of uncertainties are associated with measuring vehicle emissions in general and, specifically, in relating this data to evaluating program effectiveness (Wenzel *et al*, 2000). The uncertainties that arise in relation to the data are generally measurement uncertainty, variability (aleatory uncertainty), data reliability, and the ability of the data to represent actual on-road vehicle emissions. Each of these needs to be managed in the calculation of program benefits. No single evaluation methodology has been accepted by the I/M community (primarily consisting of scientists, regulators, and technicians), and, therefore, no one data source is accepted as being the best one for evaluation.

In addition to emissions measurements, regulatory agencies rely on emission factor models to estimate the emission contribution from mobile sources. EPA uses the series of MOBILE models. California uses its own series called EMFAC. A complete discussion of the critiques and limitations of these models is beyond the scope of this paper, but numerous studies have drawn attention to flaws in them.

Criticisms include underestimating on-road vehicle emissions, poor representation of high emitters, and poor modeling of evaporative emissions (for a more detailed discussion of emission factor models, see Fujita *et al*, 1992, GAO, 1997, Harley *et al*, 1997, Pollack *et al*, 1999, NRC, 2000, Sawyer *et al*, 2000). Despite these criticisms, states are required to use an approved emission factor model in their SIPs to demonstrate the emission reductions that will be achieved by an I/M program (USEPA, 1992).

Both emissions measurements and emission factor models were an invaluable source of information used by the groups in the evaluation process. Inspection and maintenance program evaluation is an active area of research and there is no single accepted method for the evaluation of a program like Smog Check II (USEPA, 1998, Coordinating Research Council, 2000). As was mentioned earlier, both the ARB and IMRC completed evaluations of the Smog Check II program. Table 3 shows elements that were in each of the reports, including data that were used, evaluation goals, and the treatment of uncertainty.

Each of the evaluation reports discussed the uncertainties and limitations in the available data, and, in each, the agency identified how it was planning to respond to, and manage, these uncertainties. The two styles were quite different. The IMRC report dedicated several pages, and spent a great deal of time in public meetings, discussing the uncertainties and complexities in evaluating an I/M program. In the face of this uncertainty, IMRC stated that it provided "a range of benefit estimates that reflects the uncertainty inherent in estimating tons-per-day emission reductions" (IMRC, 2000).

On the other hand, ARB briefly discussed uncertainties in the data sources and then selected one type of data on which to base its analysis, stating that it was using the "best available data from a real world standpoint" (ARB, 2000). From this point on, it did not discuss uncertainty in the data or the analysis, but only in relation to the IMRC report.

Where data were unavailable, both evaluations required assumptions to fill in the gaps. ARB used the current version of California's emission factor model, EMFAC2000, to make estimates of program performance (ARB, 2000). The IMRC evaluators made assumptions and provided bounding estimates to examine the sensitivity of its prediction of program benefits to these assumptions (IMRC, 2000).

In spite of the uncertainties, each report provides an estimate of program benefits in tons per day of emission reductions attributable to Smog Check II. As Table 3 shows, these estimates do overlap, despite differences in the methodologies and data used. Nonetheless, the fact that the two reports did not match up exactly threatened the legitimacy of the evaluation process.

Both the ARB and IMRC focused on the differences between the reports and used these differences as a basis for critiquing the other's report and defending its own. As the two reports were released to the same body of interested and affected parties, debates inevitably arose over the validity and appropriateness of each of the studies. Public debate and discussion was facilitated by the IMRC's regular, public meetings that are required in the committee's governing legislation.[9]

Each of these reports had a different regulatory mandate and sought to answer a different set of questions. Challenges arose over which data set was appropriate — roadside data versus VID data. Questions were posed about the method of analysis and, in particular, the appropriate role of models. Finally, the question arose regarding the importance and relevance of the SIP commitment as an evaluation criterion. These three debates formed the basis of the regulatory discourse that developed surrounding the evaluation process.

Uncertainty in the regulatory discourse

Given the numerous uncertainties in the available data and models, it is not surprising that uncertainty was

Table 3. Major features of the ARB and IMRC evaluation reports

Feature	IMRC Report	ARB report
Regulatory mandate	- State law requires reporting the State Legislature	- Federal law requires report to the EPA - State law requires reporting the IMRC
Question(s) answered in evaluation report	- To what extent is the Smog Check program reducing the emissions of on-road vehicles, and does program effectiveness change over time? - What underlying causal factors make the Smog Check program more or less effective? - What is the cost and cost effectiveness of Smog Check? - How can the effectiveness and cost effectiveness of the Smog Check Program be improved?	- How well is the enhanced element of the state's I/M program, Smog Check II meeting the requirements of the SIP?
Data sources used	- VID data to estimate emission reductions (exhaust and assess durability of repairs, determine program avoidance (one-cycle benefits of the program) - Roadside data to estimate emission reductions (incremental benefits of the program over basic Smog Check) - Remote sensing measurements to assess durability of repairs	- Roadside pullover data to estimate exhaust emission reductions, average fleet emission reductions (g/mile) - EMFAC 2000 model used to estimate tons-per-day emission reduction
Modeling data used	None, did include ARB's EMFAC2000 estimate for evaporative emission reductions for comparative purposes	EMFAC 2000 used to determine the effectiveness of the program as compared to the SIP, predict evaporative emission reductions
Overall predicted program benefits (tons per day)	HC[b] 86 CO[b] 1686 NO_x[b] 83	HC[a] 93 (evaporative + exhaust) CO[a] 785 NO_x[a] 27
Estimated uncertainty (high, low)	HC (40, 116) CO (864, 2235) NO_x (59, 93)	Not reported
Estimated emission reductions in "SIP currency"[c] (tons per day)	Not reported	HC 28 NO_x 12 CO not reported

[a] These numbers cannot be compared to ARB's final numbers (in the final row) because the ARB estimate is reported in "SIP currency" which is determined using the EMFAC model These estimates of emission reductions are from analysis of the roadside pullover data

[b] These figures represent the "best estimate" of emissions benefits from the Smog Check II program, including estimates of pre-inspection, pre-test repair, and removal of vehicles from the program area They do not include estimates of evaporative emission benefits

[c] The SIP estimates of program performance were calculated using the EMFAC7F model This model is now known to underestimate emissions Therefore, to reduce emissions 1 ton per day in EMFAC7F, or "SIP currency", it is necessary to reduce emissions more than 1 ton per day in the "real world" In order to compare their numbers calculated from the roadside analysis to the SIP, ARB had to translate these values into "SIP currency" (ARB, 2000, page V-1)

important in the regulatory discourse surrounding the evaluation However, in contrast to the evaluation reports that focused on uncertainties in data and models, the public discussion focused on the differences in how these uncertainties were addressed The uncertainties that were revealed and highlighted through the regulatory discourse lay in methodological and epistemological differences in the evaluation processes and not in the data More specifically, the discussion focused on the management of the uncertainties associated with evaluation in each of the reports The regulatory discourse was dominated by three debates over the selection of data, the method of evaluation, and the evaluation criterion These debates were framed in technical terms and focused on issues associated with uncertainty in evaluation data and methods, but also related to institutional commitments and agendas

Selecting data what you don't know can hurt you

Immediately, upon release of the two reports, questions arose over which was the appropriate type of data to use Each data set has its own limitations and advantages ARB argued that the IMRC's use of the VID data was not valid because it does not account for the effect of pre-inspection maintenance and repair Thus, a vehicle could have an unofficial pre-test, be repaired, and then pass the test without being registered in the VID Then the emissions benefits achieved by the pre-test and repair are not counted ARB argued that this issue invalidated the VID data as a tool for program evaluation In addition, VID data are subject to the influences of fraud and cheating that occur in the Smog Check II stations ARB argued that these issues mean that VID data are not appropriate for evaluation

The IMRC evaluators, on the other hand, while admitting limitations, argued that the VID data provided an excellent opportunity for examining diverse aspects of the program because of the large number of measurements This allows the VID data to be broken into smaller groups to look at sub-populations of the vehicle fleet In addition, the VID contains several measurements for some of the vehicles because of the change-of-ownership requirement[10] and allows for a temporal comparison of Smog Check II testing data before and after inspections

At the same time, the IMRC highlighted that the roadside data used by ARB contains potential sampling biases because of socio-economic differences across sampling areas Other biases in the data can arise from timing of the inspections and the limited population of vehicles that are captured ARB argued that roadside data are the most accurate representation of on-road vehicle emissions because you capture the vehicles in the condition that they are driven and, ideally, you measure emissions of vehicles in proportion to the amount that they are driven on the road

Evaluation method getting from data to answers

A central question raised by each of the groups was not only *what* data did the other group select, but *how* did it apply that data Each group critiqued the other's report with respect to the evaluation methodology This focus on method seemed a natural locus for criticism and critique of the reports When it became evident that the ARB study would be released at the same time as the IMRC's and that they both provided estimates of tons-per-day emission reductions, one ARB staff member said

> " our real concern became — do the numbers match up? And, more important than do the numbers match up, if the methodology is different, is it going to be as credible or accurate as the methodology that was chosen for the ARB/BAR report?"[11]

Much of the debate focused on the application of data and the response to uncertainty The debate over method became, in some ways, a battle of simplicity versus complexity The IMRC critiqued the ARB for hiding assumptions that were made in its analysis and oversimplifying the analysis The IMRC also critiqued the ARB's use of EMFAC2000, pointing to the numerous uncertainties and limitations in emissions-factor models [12] Overall, IMRC argued that the ARB was not clear in revealing the uncertainties and assumptions inherent in its analysis

The ARB defended its methodology and data selection, stating the methods used data that required the fewest "leaps of faith" [13] At the same time, the ARB pointed to the complexity of the IMRC's methodology It questioned the IMRC about why it did not use a simpler methodology, stating that a simpler method was relevant because ARB did it that way [14] Further, the ARB argued that the IMRC report did not discuss the limitations of the VID data in a manner that reflected their seriousness

The regulatory discourse was dominated by three debates: selection of data (what you don't know can hurt you); method of evaluation (getting from data to answers); and evaluation criteria (is the target 110 tons per day emission reduction)

Evaluation criteria 110 is the magic number

The third debate that dominated the regulatory discourse was over evaluation criteria One metric of success of the Smog Check II program is the 110 tons per day of emission reductions attributed to Smog Check II in the 1994 ozone SIP Given the uncertainty in the models used to predict program performance in the SIP, the relevance of that number as an evaluation metric was a point of disagreement For ARB, the SIP is a defining document, it outlines how and when the state will comply with clean air guidelines As such, the ARB emphasized the importance of the SIP commitment as an evaluation metric

> " [you] can't separate [Smog Check and the SIP] You have Smog Check because of the federal Clean Air Act and the SIP Therefore, that's the world we live in "[15]

For ARB, the SIP and the regulatory mandate that it carries create a world in which its relevance cannot be ignored, and, therefore, it defined the ARB's evaluation method

Having a different regulatory mandate, the IMRC does not imbue the SIP commitment with the same importance [16] Therefore, the IMRC viewed the SIP commitment as a regulatory artifact, and not a measure of program success that was relevant to its evaluation The IMRC's goal was focused on completing a rigorous and scientifically defensible evaluation In one public meeting, the chairperson of the IMRC stated

> " the novel and path-breaking aspect of this report is that it attempts to get out of that cycle —acknowledging the importance of the

SIP for a legal standpoint. but also acknowledging that there is a big wide world out there, lots of complex things going on with Smog Check, and we want to get a grip on those "[17]

For IMRC, the goal was to achieve scientific ideals and rigor, further evidenced by its employment of contractors from Lawrence Berkeley National Laboratory, a highly respected scientific institution, to perform the evaluation and the chairperson's fierce attempts to maintain a separation between analytical results and policy recommendations

The clash over these different interpretations of the SIP commitment remained firmly entrenched throughout the evaluation process In its final report, ARB wrote that, "there are still significant disagreements between the I/M Review Committee and [the] ARB regarding the need and importance of considering the SIP targets, and program performance in relation to those targets" (ARB, 2000, page ES-5) Likewise, in its final report, the IMRC states that the "[r]esponsibility for evaluating California's SIP compliance rests solely with the ARB" (IMRC, 2000, page ES-6)

Uncertainty in evaluation reports and discourse

In a sense, the concept of uncertainty changes as we look at the evaluation reports and the regulatory discourse surrounding the evaluation process In the reports. uncertainty is discussed in terms of measurement issues, limitations in data, and complexities in models However, in the regulatory debates and discourse, uncertainties were discussed in terms of selection of data, methods of evaluation, and selection of evaluation criteria For example, the debate over data selection focused on what the data can and cannot tell you, not how uncertain a given measurement is

These debates highlight the influence of institutional commitments and responsibilities on the use of scientific information in the regulatory process Even though the issues that formed the basis of the debates were framed in technical terms (modeling vs empirical data, roadside pullover data vs VID data) these issues were very closely tied to institutional frames and commitments ARB defended its methodology and data selection highlighting the importance of the SIP commitment and its relevance to ARB's methods and evaluation For ARB. this creates a simplicity in its mission and methods that is reflected in its arguments in the debate For ARB, this analysis was simply meant to "check off a box" [18]

The IMRC, on the other hand, defended its representation of the uncertainties and its response to the uncertainties as being more robust Further, in its final report, the IMRC stated that the SIP was not its responsibility For the IMRC, the SIP does not define its institutional mission or responsibility IMRC valued the scientific credibility of its report, which is clear in its focus on the robustness of its analysis as well as in its focus on the complexity of the evaluation process This importance is evident in the IMRC's chairperson's description of the report as "novel and path-breaking' [19]

The uncertainties that dominated the regulatory discourse were not only related to the uncertainty in the data and models, but to how that relates to the institution's goals and responsibilities In one sense, this creates a new layer of uncertainty introduced by the uptake and application of uncertain information into evaluation methods and results Therefore, understanding uncertainty and its impact on regulatory decision making is incomplete if uncertainties in the scientific methods and data are considered alone Because of the relationship between evaluation methods and regulatory goals, the dominant uncertainty in the discourse is no longer one that can be described through statistical or analytical methods [20] One way to better understand these uncertainties, as is shown by this case. is through descriptive or narrative analysis

Discussion and implications

The Smog Check II evaluation process is a highly uncertain and contentious regulatory process that demonstrates the influence that science and uncertainty have on the construction of arguments The available data and models are important to the process, but even more significant is how parties select amongst the information, interpret and respond to uncertainties. and set criteria for evaluation

The two evaluation reports were never reconciled and neither the ARB nor the IMRC ever fully accepted the other's methods and results The reason for the lack of resolution lies in the differences in the groups' institutional goals and commitments, and the ways in which the two groups selected data, analyzed that data, and set regulatory performance standards that reflect these goals

These differences not only created the framework within which each group conducted its evaluation, but they also shaped the regulatory debates and discourse In the reports, uncertainties were discussed and analyzed with respect to the evaluation methodology Then, in the debates and discourse, this discussion extended to the institutional goals and commitments that influenced discussion of data and methods in the report With this shift, the uncertainties that became the focus of the debate were not only related to uncertainties in the data, but to how those uncertainties were treated and responded to in the two reports

The process of constructing a regulatory argument, in this case, about how Smog Check II is performing, is complex Without analyzing and understanding how the ARB and the IMRC each selected data and methods to perform their evaluation, the source of disagreement is elusive Disagreement over the value of data sources and the appropriate evaluation methodology are not linked to purely technical or scientific sources, but to institutional goals and commitments, or to the context in which the evaluation is being conducted

Understanding the debates and uncertainties observed in the regulatory discourse requires an analysis of the scientific, institutional, and political components of the regulatory process as a whole and not as separate parts Other researchers have observed and noted the influence of interests and goals on the construction of arguments in policy debates (see, for example, Herrick and Jamieson, 1995 on acid rain. Soneryd and Uggla, 2000 on planning decisions in Sweden, and Majone, 1989, Roe, 1994, Schon and Rein, 1994 for more general discussion)

Because of the importance of how arguments are constructed in the regulatory discourse, the Smog Check II evaluation process demonstrates a crucial weakness in utilitarian decision analytic techniques for use in understanding and developing environmental decision-making frameworks Utilitarian methods such as cost–benefit analysis are 'ends-oriented', focusing solely on decision outcomes These methods cannot account for the context of the environmental decision making and regulatory processes In other words, they do not incorporate information on the formation of values or arguments

For example, Apostolakis and Pickett (1998) attempted to implement an analytic-deliberative process, like that envisioned by the National Research Council (NRC, 1996), for a remediation project They used the analytic-hierarchy process to assess the priorities of stakeholders as input to a multiattribute utility analysis Despite several surveys and discussions with the participants, the decision analytic outcome based on the multiattribute utility analysis was, in the end, unacceptable to the stakeholders (Apostolakis and Pickett, 1998) [21]

The reason for the failure to find an acceptable solution lay in the fact that the decision analytic methods could not illuminate the stakeholders' underlying, long-term, and rather negative feelings about the institution responsible for cleaning up the site These feelings created the context within which the decision was to be made and they were not included in the analytic-deliberative process

The Apostolakis and Pickett case illustrates the weakness in utilitarian methods as applied to environmental decisions Combined with the evidence of the influence of institutional goals and commitments on the uptake and use of science and the processing of uncertainty in environmental regulatory process from our analysis, these cases demonstrate that an alternative framework is needed to understand environmental regulatory decision making Our analysis demonstrates the value of a narrative and descriptive approach for understanding the influence of institutional goals and commitments on the processing of science and uncertainty and the construction of arguments and debates in the environmental regulatory process

As our analysis of the Smog Check II evaluation process reveals, the uptake and use of scientific information and uncertainty is influenced by the institutional context of the decision making To understand controversy and debate in the environmental regulatory process, this influence needs to be recognized in the methods used for the development of frameworks for environmental decision making Our case study demonstrates the usefulness of narrative and descriptive analysis of the processing of uncertainty in the regulatory process for achieving this goal

Other methodologies that incorporate narrative and descriptive analysis of the environmental regulatory process include frame analysis as described by Schon and Rein (Schon and Rein, 1994, Rein and Schon, 1996), the STS, boundary approach employed by Jasanoff (1990), or narrative policy analysis as described by Roe (1994) Each of these methods has the advantage of examining the construction of arguments and their interaction in the regulatory process Like the method employed in this analysis, these approaches to understanding and evaluating environmental decision making allow for the consideration of the context of decision making, which is crucial for the development of effective environmental decision making frameworks

Notes

1 The NAAQS are set by the EPA for six criteria pollutants carbon monoxide, ozone, nitrogen dioxide, sulfur dioxide, particulate matter, and lead

2 The term "attainment" refers to whether or not an area of the country meets the national ambient air quality standard for a given pollutant Areas are classified by the EPA according to their degree of non-attainment extreme, serious, severe, and worse States with areas that are out of attainment are required to submit a plan, known as a State Implementation Plan, to EPA, demonstrating how and when the non-attainment areas will come into compliance with the air quality standards Areas with more severe air pollution are allowed more time to come into attainment

3 The IM240 is a 240-second dynamometer test that is a subset of the Federal Test Procedure, the test used to certify that new vehicles meet emission standards and fuel efficiency requirements

4 The areas of the state subject to Smog Check II are the urbanized portions of Los Angeles, Ventura, and San Diego, the metropolitan area of Sacramento, the Southeast Desert, and the San Joaquin Valley

5 Excerpt from an IMRC public meeting, 3 May 2000 in San Francisco, California

6 Excerpt from an IMRC public meeting, 19 June 2000 in Sacramento, California

7 IMRC Member, interviewed by Louise Wells Bedsworth, Berkeley, California, 18 November 1999

8 The driver may notice the set-up on the side of the road, and in some cases it is used to inform drivers of their vehicle's emissions (see, for example, Bishop *et al*, 2000), but, for the most part, RSD can be implemented and used without disrupting traffic flow

9 California Health and Safety Code 44021, 44021 (a)(4) specifically discusses public meetings

10 The change-of-ownership requirement is designed to protect vehicle buyers by requiring that vehicle sellers obtain a

Smog Check certificate for that vehicle prior to the sale

11 Interview at ARB, Sacramento, California, 5 June 2001

12 To illustrate the contentious nature of the use of emission-factor models, it is worth noting that the BAR did not agree with the ARB's use of the model either The ARB and BAR began work on the Smog Check II evaluation together In fact, analysts from BAR completed most, if not all, of the roadside data analysis When ARB decided to use the EMFAC2000 model in the evaluation report, BAR asked to have its name removed from the report From that point on, the ARB took the lead on the evaluation report In public meetings, representatives of BAR would answer specific questions relating to data or the roadside analysis, but essentially all the other input was provided by ARB representatives

13 IMRC meeting, 3 May 2000 San Francisco, California

14 IMRC meeting, 3 May 2000 San Francisco, California

15 IMRC meeting, 19 June 2000 Redondo Beach, California

16 It is important to note here that the IMRC is made up of representatives from all interested and affected parties In this debate over the relevance of the SIP, there was disagreement within the committee The member who represents an air-quality management district also viewed the SIP commitment as a number that carried great importance in his area, a major non-attainment area of the state In fact, this debate and the fact that the IMRC would not include a discussion of the SIP was a major factor in his decision not to vote to accept the IMRC evaluation report

17 IMRC meeting, 19 June 2000 Redondo Beach, California

18 Interview at ARB, Sacramento, California, 5 June 2001

19 IMRC meeting, 19 June 2000, Redondo Beach, California

20 This influence of interests and values on the processing of uncertainty in regulatory debates has been noted by Stirling in his analysis of precaution in risk management processes (Stirling, 1999) They term the combination of risk, uncertainty, ignorance and ambiguity as "incertitude" to delineate it from the "traditional" definition of uncertainty In their case work, they note the tendency to try to treat ignorance and intractable uncertainty using probabilistic methods, despite their inadequacy

21 A series of papers discuss this attempt to implement the analytic-deliberative process using utilitarian decision-analytic tools The one cited in the text is an overview, others include (Accorsi *et al*, 1999a, 1999b)

References

Accorsi, Roberto, George Apostolakis and Enrico Zio (1999a), "Prioritizing stakeholder concerns in environmental risk management", *Journal of Risk Research*, 2(1), pages 11–29

Accorsi, R E Zio and G E Apostolakis (1999b), "Developing utility functions for environmental decision making", *Progress in Nuclear Energy*, 34(4), pages 387–411

Apostolakis George E and Susan E Pickett (1998), "Deliberation integrating analytical results into environmental decision making involving multiple stakeholders", *Risk Analysis*, 18(5), pages 621–634

ARB, Air Resources Board (1994), *California State Implementation Plan, Volumes I–IV* (www arb ca gov/sip/sip htm)

ARB, Air Resources Board (2000), *Evaluation of California's Enhanced Inspection and Maintenance Program (Smog Check II)*, 12 July 2000, Sacramento

Bishop, G A and D H Stedman (1996), "Measuring the emissions of passing cars", *Accounts of Chemical Research*, 29(10), pages 489–495

Bishop, Gary A, *et al* (2000), "Drive-by motor vehicle emissions immediate feedback in reducing air pollution", *Environmental Science and Technology*, 34(6), pages 1110–1116

Campbell, Brian L (1985), "Uncertainty as symbolic action in disputes among experts", *Social Studies of Science*, 15, pages 429–453

Coordinating Research Council (2000), "Session IX evaluating I/M programs", presented at 10th On-Road Vehicle Emissions Workshop, San Diego, CA

Elzinga, A (1997), "From Arrhenius to megascience interplay between science and public decision making", *Ambio*, 26(1), pages 72–80

Fujita, Eric M, *et al* (1992), "Comparison of emission inventory and ambient concentration ratios of CO, NMOG, and NOx in California's South Coast Air Basin", *Journal of the Air and Waste Management Association*, 42(3), pages 264–276

Funtowicz, Silvio, and Jerry Ravetz (1990), *Uncertainty and Quality in Science for Public Policy* (Kluwer Academic Publishers, Dordrecht)

Funtowicz, S O and J R Ravetz (1992), "Three types of risk assessment and the emergence of post-normal science", in Sheldon Krimsky and Dominic Golding, (editors), *Social Theories of Risk* (Praeger, Westport)

GAO (1997), *Air Pollution Limitations of EPA's Motor Vehicle Emissions Model and Plans to Address Them* (Government Accounting Office, Washington DC, GAO/RCED-97-210)

Gieryn, Thomas F (1983), "Boundary-work and the demarcation of science from non-science strains and interests in professional ideologies of scientists", *American Sociological Review*, 48(December), pages 781–795

Gieryn, Thomas F (1999), *Cultural Boundaries of Science Credibility on the Line* (The University of Chicago Press, Chicago)

Harley, Robert A, Robert F Sawyer and Jana B Milford (1997), "Updated photochemical modeling for California's South Coast Air Basin comparison of chemical mechanisms and motor vehicle emission inventories", *Environmental Science and Technology*, 31(10), pages 2829–2839

Herrick, Charles, and Dale Jamieson (1995), "The social construction of acid rain some implications for science/policy assessment", *Global Environmental Change*, 5(2), pages 105–112

Hong, Yuan and George Apostolakis (1993), "Conditional influence diagrams in risk management", *Risk Analysis*, 13(6), pages 625–636

IMRC (2000), *Smog Check II Evaluation*, 19 June 2000, Sacramento

Jager, Jill (1998), "Current thinking on using scientific findings in environmental policy making", *Environmental Modeling and Assessment*, 3, pages 143–153

Jasanoff, Sheila (1986), *Risk Management and Political Culture* (Russell Sage Foundation, New York)

Jasanoff, Sheila (1987), "Contested boundaries in policy-relevant science", *Social Studies of Science*, 17, pages 195–230

Jasanoff, Sheila (1990), *The Fifth Branch Science Advisers as Policymakers* (Harvard University Press, Cambridge)

Jasanoff, Sheila and Brian Wynne (1998), "Science and decision making", in Steven Rayner and Elizabeth L Malone (editors), *Human Choice and Climate Change, Volume I The Societal Framework* (Battelle Press, Columbus)

Keeney, Ralph L, and Howard Raiffa (1976), *Decisions with Multiple Objectives Preferences and Value Tradeoffs* (John Wiley and Sons, New York)

Lawson, Douglas R (1993), "'Passing the test' — human behavior and California's Smog Check Program", *Journal of the Air and Waste Management Association*, 43, pages 1567–1575

Lawson, Douglas R (1995), "The costs of 'M' in I/M — reflections on Inspection/Maintenance Programs", *Journal of the Air and Waste Management Association*, 45, pages 465–476

Majone, Giandomenico (1989), *Evidence, Argument , and Persuasion in the Policy Process* (Yale University Press, New Haven)

Merkhofer, Miley W, and Ralph L Keeney (1987), "A multiattribute utility analysis of alternative sites for the disposal of nuclear waste", *Risk Analysis*, 7(2), pages 173–194

Morgan M Granger and Max Henrion (1990), *Uncertainty A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge University Press, Cambridge)

NRC (1996), *Understanding Risk Informing Decisions in a Democratic Society* (National Academy of Sciences, Washington DC)

NRC (2000), *Modeling Motor Vehicle Emissions* (National Academy Press, Washington DC)

Ozawa, Connie (1996), "Science in environmental conflicts", *Sociological Perspectives*, 39(2), pages 219–230

Pollack, Alison K, *et al* (1999), *Investigation of Emission Factors in the California EMFAC7G Model* (Coordinating Research Council, Atlanta Georgia)

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997), *Risk Assessment and Risk Management in Regulatory Decision-Making (Final Report Volume II)* (Presidential/Congressional Commission on Risk Assessment and Risk Management, Washington DC)

Reckhow, Kenneth H (1994), "A decision analytic framework for environmental analysis and simulation modeling", *Environmental Toxicology and Chemistry*, 13(12), pages 1901–1906

Rein, Martin, and Donald Schön (1996), "Reframing policy discourse", in Frank Fischer and John Forester (editors), *The Argumentative Turn in Policy Analysis and Planning* (Duke University Press, Durham)

Roe Emery (1994), *Narrative Policy Analysis Theory and Practice* (Duke University Press, Durham)

Rowe, William D (1994), "Understanding uncertainty", *Risk Analysis*, 14(5), pages 743–750

Sawyer, R F, *et al* (2000), "Mobile source critical Review 1998 NARSTO assessment", *Atmospheric Environment*, 34, pages 2161–2181

Schon, Donald A and Martin Rein (1994), *Frame Reflection Toward the Resolution of Intractable Policy Controversies* (Basic Books, New York)

Shackley, Simon and Brian Wynne (1996), "Representing uncertainty in global climate change science and policy boundary-ordering devices and authority", *Science, Technology, and Human Values*, 21(3), pages 275–302

Shrader-Frechette, Kristin (1996), "Methodological rules for four classes of uncertainty", in John Lemons (editor), *Scientific Uncertainty and Environmental Problem Solving* (Blackwell Science, Cambridge)

Soneryd, Linda, and Ylva Uggla (2000), "Politics as a struggle over definition — two case studies", *Environmental Science and Policy*, 3, pages 277–286

Star, Susan Leigh (1985), "Scientific work and uncertainty", *Social Studies of Science*, 15, pages 391–427

Stedman, Donald H, *et al* (1997), "On-road evaluation of an automobile emission test program", *Environmental Science and Technology*, 31(3), pages 927–931

Stedman, Donald H, Gary A Bishop and Robert S Slott (1998), "Repair avoidance and evaluating inspection and maintenance programs", *Environmental Science and Technology*, 32(10), pages 1544–1545

Stirling, Andrew (1999), *On Science and Precaution in the Management of Technological Risk* (Final Report of a Project for the EC Forward Studies Unit) (ESRC Global Environmental Change Programme, Sussex)

USEPA (1992) "Inspection and maintenance program requirements final rule", *Federal Register*, 40 CFR Part 51, Subpart S (5 November 1992)

USEPA (1994), *Clean Cars for Clean Air Inspection and Maintenance Program* (Office of Mobile Sources, Ann Arbor, EPA 400-F-92-016)

USEPA (1995), *I/M Briefing Book Everything You Ever Wanted to Know About Inspection and Maintenance* (Office of Air and Radiation, Washington DC)

USEPA (1998), *Inspection and Maintenance (I/M) Program Effectiveness Methodologies* (Office of Mobile Sources, Ann Arbor, EPA420-S-98-015)

van Asselt, Marjolein B A, Arthur H W Beusen and Henk B M Hilderink (1996), "Uncertainty in integrated assessment a social scientific perspective", *Environmental Modeling and Assessment*, 1 pages 71–90

van Asselt Marjolein B A, and Jan Rotmans (1996), "Uncertainty in perspective", *Global Environmental Change*, 6(2), pages 121–157

Wenzel, Tom, Brett C Singer and Robert Slott (2000), "Some issues in the statistical analysis of vehicle emissions", *Journal of Transportation Statistics*, 3(2), pages 1–14

Wynne, Brian (1987), "Uncertainty — technical and social", in Harvey Brooks and Chester L Cooper (editors), *Science for Public Policy* (Pergamon Press, Oxford)

Wynne, Brian (1992), "Uncertainty and environmental learning reconceiving science and policy in the preventative paradigm", *Global Environmental Change*, 2 June, pages 111–127

Volume 29 Number 1 February 2002

SPP

Science and Public Policy

ISSN 0302-3427

Published from Great Britain by Beech Tree Publishing

0302-3427(200202)29 1 1-G

Science and Public Policy

Volume 29 Number 1 February 2002

Science and Public Policy

Main articles in this issue — Full summaries: see individual articles

Published from Great Britain by Beech Tree Publishing, 10 Watford Close Guildford, Surrey GU1 2EP

Some recent articles from **Science and Public Policy**

The American research university in America's *de facto* technology policy, Michael Crow (Provost (Research), Columbia University, USA) *et al* February 2001

Academic research in Europe Keith Pavitt (SPRU, UK) Dec 2000

Are government investments in R&D and market environment needed for indigenous private R&D in LDCs? Evidence from Korea. Sun G Kim (Taejon University, Korea), Feb 2000

Technology policy in the US and EU: shifting orientation towards technology users, Nicholas S Vonortas (George Washington University USA), April 2000

Diversity and identity the merger of five research councils in Norway, Hans Skoie (NIFU Norway) April 2000

Patents in a world of complex technologies Don Kash (George Mason University USA) *et al* February 2001

Changing S&T policy cultures phases and trands in S&T in India V V Krishna (J Nehru University India) June 2001

Services and the search for innovation indicators a review of national and international surveys, Faiz Gallouj (University of Lille, France) *et al* Aug 1999

Research excellence and patented innovations, Diana Hicks Francis Narin *et al* (CHI Research USA), October 2000

Technical roles and success of US federal laboratory-industry partnerships, Barry Bozeman (GeTech, USA) *et al*, June 2001

Technology transfer or incubation? Technology business incubators and S&T parks in the Philippines, S Macdonald (Sheffield University, UK) *et al*, October 2001

The politics of export advice: lessons from the early history of the BSE saga, Erik Millstone *et al* (SPRU, UK), April 2001

Analysis of MITI's 'Visions' and challenges for Japan's technology policy-making mechanisms Chih-iro Watanabe *et al* (Tokyo Institute of Technology) February 1999

Science and technology issues for legislators Gary Kass (Parliamentary Office of S&T, UK), October 2000

Promotion of co-operative research a Spanish experience, Juan Acosta Ballesteros (University of Laguna, Spain) *et al*, October 2000

Contribution of basic research to the Irish innovation system, Erik Arnold *et al* (Technopolis consulting, Brighton, UK), April 2001

SOME SPECIAL ISSUES

Democracy in S&T policy advice in Europe, guest edited by M de Jong and M Mentzel (Netherlands), December 2001

Sense and nonsense in S&T productivity indicators, Remi Barré (Observatoire des S&T, France) 1 of 8 papers on **Benchmarking RTD policies**, guest edited by Nikos Kastrinos (EC, Brussels), August 2001

Interactive social science, guest edited by Chris Caswill (ESRC, UK) and Elizabeth Shove (Lancaster, UK), Mike Gibbons, Steve Woolgar, Arie Rip, etc June 2000 See page 11

Technology transfer and Eastern Europe, guest edited by Henry Etz-kowitz, August 2000

Consensus conferences, focus groups, citizens' panels, etc, guest edited by Simon Joss (Uni of Westminster, UK), Oct 1999

Changes in Europe's public sector research, guest edited by Jacky Senker (SPRU), Dec 2000

Scientific expertise and political accountability paradoxes of science in politics, Peter Weingart (Bielefeld Germany), 1 of 7 related papers June 1999

All 30 issues, 1996-00: £100, US$160 or €164
Some may be photocopies

Subscription information...

Published bimonthly (February, April, June, etc) A4 size, 488 pages in 2001 464 in 2000 452 in 1999, 424 in 1998 on acid-free paper Free online access for hard copy subscribers at www catchword com Back issues available, start with any issue included by online aggregators and abstracting and document delivery services Index in December issues ISSN 0302-3427 (print) and 1471-5430 (electronic) Multi-year subscriptions include a 20% discount 2002 issues form volume 29 For prices see follow-up (next column)

... and follow-up through

www scpol demon co uk

+44 1483 824871

+44 1483 567497

Bill Page, Beech Tree Publishing
10 Watford Close, Guildford
Surrey GU1 2EP, UK