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Robert N. Stavins

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1 Introduction

It is an honour to write this chapter about the contributions of my mentor, Robert N. Stavins, to the field of environmental economics. Rob has spent his entire academic career at Harvard, first as a graduate student in the Department of Economics and then as a faculty member at the Harvard Kennedy School of Government. Together with Marty Weitzman (see Chapter 29 in this volume), Rob built the environmental economics programme at Harvard over decades and his work largely defines the Harvard approach to the field. Rob's work has always been at the intersection of economics and policy—bringing rigorous theoretical and empirical insights to the most pressing environmental policy problems, from wetlands depletion to acid rain to the fundamental environmental challenge of our time, climate change.

Rob's applied policy focus was surely shaped by his non-traditional path to the professoriate (discussed in more detail in Section 2). At a time when it was common for students in economics to pursue a PhD immediately after finishing their undergraduate degree, Rob served in the Peace Corps, pursued a Master's degree in economic development, and worked for the Environmental Defense Fund (EDF) before accepting an offer of admission to the Harvard PhD programme in economics. This unique background made him

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particularly well-suited to bridge academic insights from economics with real-world policy applications.

As you will see in Section 3, Rob's main contributions to the field can be placed into five categories. The first category of research includes broad insights on the role of economics in environmental and resource policy. This includes the role of benefit–cost analysis, discounting, the impact of regulation on manufacturing activity and international competitiveness, business and the private sector in environmental governance, and property rights in understanding and addressing environmental and resource problems. The second category focuses on the economics of policy instrument choice—particularly focused on the role of market-based policy instruments, such as pollution taxes and cap-and-trade systems in environmental policy. The third category examines questions of dynamic optimisation of environmental policy by focusing on the impact of policy choices on technological change. The fourth category explores the economics of natural resources and land-use change. Finally, all of these strands are brought together in Rob's extensive work on the economics of climate change—both at the global and domestic levels.

In addition to his prolific scholarly activity, Rob has also played a direct role in environmental policy. He has served on a Congressional task force on the use of market-based instruments, as a member of the US Environmental Protection Agencies Science Advisory Board on economics, and as a member, and lead author, of a major report on the socioeconomic impacts of climate change written by the Intergovernmental Panel on Climate Change (IPCC). Through these engagements, Rob has arguably done as much as any other scholar to bring the insights of economics into practice.

2 Biographical Sketch

Rob completed his undergraduate studies at Northwestern University where he initially intended to study astronomy and astrophysics, but switched gears and earned a BA in philosophy. Following graduation, he joined the Peace Corps where he spent four years working with a small agricultural extension in Sierra Leone on paddy rice development. When he returned to the US, he enrolled in a Master's programme at Cornell University. Based on his experience in Sierre Leone, he originally planned to earn a professional degree in international development. But while at Cornell, Rob took classes in agricultural economics, which was also related to his work in Sierra Leone. Ultimately, he found agricultural economics more

to his liking, in part because of the quantitative approach to address social questions. His MS thesis, "Forecasting the Size Distribution of Farms: A Methodological Analysis of the Dairy Industry in New York State", used a variable Markov transition probability matrix, the cells of which were estimated econometrically in a multinomial logit framework. His thesis received the Outstanding Master's Thesis Award in the national competition of the American Agricultural Economics Association.

At Cornell, Rob also was able to teach at university level for the first time, an experience he enjoyed. Yet, despite his skill in teaching and the success of his thesis research, after finishing his MS degree he did not immediately enter a PhD programme. Rather, he crossed the country to Berkeley, California, where he worked with the EDF on, among other projects, a benefit–cost analysis of preserving the Tuolumne River which is located in and near Yosemite National Park in California and which was being considered for a hydroelectric dam project (Stavins 1983). Rob's work on this project was important in at least two ways. First, it was a rigorous economic analysis done within a leading environmental non-profit when nearly all environmental non-profits had no economists on their staff and were sceptical of economics in general, and benefit–cost analysis, in particular. Second, at a time when the federal government was mandating benefit–cost analysis of all new major regulations and many environmentalists and advocates feared this analysis would inevitably lead to deregulation and excess economic development, Rob's benefit–cost analysis supported preservation of the River in its current state over hydroelectric development, showing that benefit–cost analysis can be an important, and non-partisan, decision aid. These insights foreshadow themes that will recur throughout Rob's research career—that rigorous and quantitative economic analysis can be applied to environmental problems and that such analysis can be used to enhance environmental quality and preserve resources and not only as a tool to deregulate and promote development.

After working at EDF for several years, Rob decided that he needed to pursue an additional degree to further his career aspirations. After briefly contemplating enrolling at Stanford Law School, he instead moved back to the east coast where he enrolled as a PhD student in the Economics Department at Harvard University. Rob's decision to attend Harvard was fortuitous for him and for Harvard, an institution that he would call home his entire academic career. While there was no formal field in environmental economics, Harvard did allow students to create their own field, which Rob did. His dissertation committee included Joseph Kalt, Zvi Griliches and Adam Jaffe. All three were supportive of Rob's desire to use economics in environmental applications despite their primary focus being in other research

areas—Kalt in energy, and Griliches and Jaffe in the economics of technological change. Their influence will be seen throughout Rob's research career as he explores questions of technological change and energy use but with applications to environmental policy. At Harvard, Rob also met his wife Joanna, who was a fellow PhD student. Together they have two children, Daniel and Julia. During this time, Rob also met Lawrence (Larry) Goulder who was a new professor at Harvard and became a lifelong friend and mentor.

Rob's dissertation research focused on the economic drivers of, and the economic consequences of, wetlands depletion, a major resource issue. Historically, wetlands were known, far less poetically, as swamps, and they were frequently filled to create additional land for economic development. But wetlands provide critical ecological services, including flood protection, filtering groundwater and providing habitat for myriad species. Rob's dissertation estimated the effect of federal policies on decisions about wetland management by private landowners and the socially efficient level of wetlands based on estimates of the ecological benefits they provide (Stavins 1990; Stavins and Jaffe 1990).

Rob had never intended an academic career. Rather, he thought he would return to EDF upon graduation, but during the course of his doctorate, Rob's priorities shifted and he realised he wanted an academic career, albeit one with a heavy dose of policy application. It is not surprising that when he received an offer of an Assistant Professor position in 1988 from what was then the Kennedy School of Government at Harvard (now the Harvard Kennedy School) he readily accepted. Rob spent his career at the Kennedy School where he was promoted to Associate Professor (which is an untenured title at Harvard) in 1992 and to Full Professor with tenure in 1997. In 1998, he was appointed the Albert Pratt Professor of Business and Government.

Just prior to graduating from Harvard with his PhD and before beginning his appointment at the Kennedy School, Rob received a phone call from Senator Tim Wirth (D, CO) asking him to participate in a project he was sponsoring jointly with Senator John Heinz (R, PA) to 'inject innovative ideas for environmental protection' into the presidential campaign for both George H.W. Bush (R) and Michael Dukakis (D) (see Stavins 1988). The project, which became known as Project 88, focused particularly on the potential use of market-based instruments for environmental protection.

During the summer and fall of 1988, Rob worked on Project 88 nearly full time. He assembled a team of scholars, government officials, business leaders, and environmental activists and jointly the team wrote "Harnessing Market Forces to Protect Our Environment: Initiatives for the New President" (Stavins 1988), which contained just shy of forty recommendations for

the use of market-based instruments to address environmental and resource issues. The report garnered significant attention and influenced policy decisions almost immediately. The cap-and-trade programme written into the Clean Air Act Amendments of 1990, passed by Congress and signed by President Bush, was one of the recommendations from Project 88. Market-based approaches would dominate discussions of environmental policy for the next several decades. While Rob would become well-known for his research on market-based instruments (as will be clear in Section 3), it is important to note that at the time he was called by Senator Wirth he had not conducted any scholarly research in this area. He was recommended to Wirth by his new boss, Graham Allison, the dean of the Kennedy School. A fortuitous recommendation for Rob, for the Kennedy School and for Harvard.

Rob's service with Project 88 was only the first of many forays into the policy sphere. Over his career, Rob has served as a member of the Environmental Economics Advisory Committee of the US Environmental Protection Agency's (EPA) Science Advisory Board, where he helped write guidelines on how the agency should conduct benefit–cost analysis. He has also been a member of the Executive Board of the US EPA Science Advisory Board. Rob organised and taught an executive education programme for mid-career staff at the US EPA on the role of economics in environmental policy. Most recently, he served as a lead author of the second and third assessment reports and a coordinating lead author of the fifth assessment report by Working Group III (socioeconomics) of the IPCC. He also is frequently quoted in the media and writes his own blog, "An Economic View of the Environment", and hosts a podcast, "Economic Insights: Conversations on Policy and Practice from the Harvard Environmental Economics Program".

3 Contributions to Environmental Economics

Rob's contributions to environmental economics span over 30 years and hundreds of peer-reviewed papers, book chapters, government reports, judicial amicus briefs and other publications. But in reviewing his extensive work in light of the biography in Section 2, one can see that his contributions build on, and were shaped by, key experiences in his life. In this section, I organise his contributions around five major themes. The first is methods of policy analysis, including benefit–cost analysis, work that began at EDF and the Tuolumne River. The second category is the economics of policy instruments, particularly market-based instruments which is work that grew out of his experience with Project 88. The third category is the economics

of technological change, particularly technology change driven by environmental regulations, work that dates back to his graduate school days with Griliches and Jaffe. The fourth category is natural resource economics and the economics of land-use change which builds off his dissertation research. The fifth category is the economics of climate change which brings together many of the intellectual threads in the other four categories as climate change, the defining environmental issue of our time, requires benefit–cost analysis, economic analysis of policy instruments, an understanding of the economics of technological change, and the economics of natural resources which plays a key role in both potential mitigation of climate change (through sequestration of carbon in forests and oceans) and also is a key recipient sector of damages from climate change. Many of Rob's papers span multiple categories, but for the purposes of this chapter I have somewhat arbitrarily assigned them to a single category. The remainder of this section outlines Rob's contributions in each of these five areas.

3.1 The Role of Economics in Environmental Policy

The decade of the 1980s was a period of significant economic deregulation in the US as airlines, telecommunications companies, railroads and other major industries were deregulated to promote competition. During the Regan Administration, benefit–cost analysis became required for all new major regulations (i.e. costing the economy over $100 million per annum) (Executive Order 12291 1981). While economic deregulation and benefit–cost analysis for new regulations are not necessarily linked, there was a strong feeling among the environmental community that benefit–cost analysis was a tool for deregulation and was inappropriate for use in environmental policy (see, for example, Kelman 1981). But as Rob's work with EDF on the Tuolumne River demonstrated, benefit–cost analysis can also demonstrate when, for economic reasons, preservation of a resource or reduction of environmental damages is efficient. To help bridge the gap between the reality of benefit–cost analysis and its perception, Rob published, with co-authors, two pieces in high-profile and broad scientific journals that argued for the role of economics benefit–cost analysis in environmental policy. The first paper, "Is There a Role for Benefit–Cost Analysis in Environmental, Health, and Safety Regulation?", was co-authored with Kenneth Arrow et al. and appeared in *Science* in 1996 (Arrow et al. 1996). The second paper, "How Economists See the Environment", appeared in *Nature* and was co-authored with Don Fullerton and responds to several myths that non-economists have about environmental economics (Fullerton and Stavins 1998).

Rob has also addressed the topic of discounting, which while standard in economics and finance, is controversial in some environmental policy circles (see, for example, Revesz 1999). In "Discounting: An Eye on the Future", published in *Nature*, Rob and co-author Lawrence Goulder clarify the economic practice of discounting (Goulder and Stavins 2002). They note that some concern among non-economists about discounting stems from uncertainties in estimating the future effects of policy. They argue that while these uncertainties are significant, they should not be addressed by discounting but rather through more traditional analytic means of handling uncertainty, such as through Monte Carlo analysis. The latter point, on the use of Monte Carlo analysis as an analytic tool for addressing uncertainty in regulatory impact analyses, was expanded upon in Rob's paper with Judson Jaffe entitled "On the Value of Formal Assessment of Uncertainty in Regulatory Analysis", published in *Regulation & Governance* (Jaffe and Stavins 2007).

Another important debate between environmental economists and other scholars concerns the effect of environmental regulation on the competitiveness of US manufacturing. The standard view is that environmental regulation drives up costs and hurts American manufacturing relative to manufacturing in countries that do not have such stringent regulations. But prominent business school scholar Michael Porter and his co-author Claas van der Linde (1995) argued that regulation actually promotes innovation among firms and can increase the competitiveness of US firms. Together with Adam Jaffe, Steven Peterson and Paul Portnoy, Rob assessed the empirical evidence on the impact of regulation on competitiveness. In their review of the studies on this topic they find little support for environmental regulation being a causal factor in firms' decisions on where to locate manufacturing activity. Other factors, particularly labour costs, were more substantial determinants of location. But they also found no empirical support for the notion that environmental regulation improved innovation and enhanced international competitiveness (Jaffe et al. 1995).

While traditionally environmental policy has been thought to be the domain of government regulation, over the last several decades there have been increasing pressures on businesses to go beyond compliance with environmental regulations and to promote sustainability and environmental protection through their internal processes, purchases and products. These features of private environmental governance have historically been referred to as corporate social responsibility and, more recently, by environmental, social and corporate governance, representing the three pillars of non-financial factors that firms should include in their analysis of their operations.

This private governance of the environment can be a supplement to, or a direct replacement of, more traditional government regulation. The paper "Corporate Social Responsibility Through an Economic Lens" examines several key concepts related to corporate social responsibility, including: (a) whether firms are allowed to sacrifice profits in the social interest and maintain their fiduciary responsibilities to shareholders; (b) if they are allowed to, can they functionally do so and remain competitive in their market; (c) to what extent are firms actually engaged in this type of behaviour; and (d) is it socially efficient for firms to engage in corporate sustainability in the absence of regulation (Reinhardt et al. 2008). They find that firms have the legal authority to act in the public interest, even at the expense of profits. Whether they can sustain these activities in the market is critically dependent on the features of the market—while not sustainable in perfectly competitive markets, this activity can be maintained in many other market conditions. Finally, they find that firms do engage in this activity, but it is not always socially efficient. The one case where it is efficient is if the regulated level of environmental protection is too low—in this case, firms going beyond compliance reduce welfare losses from the inefficient government regulation.

Rob has authored many well-cited review articles on environmental and resource economics. I will not highlight all of them as many of these topics are well covered by his primary research papers. But I want to highlight one, which is "The Problem of the Commons: Still Unsettled After 100 Years" (Stavins 2011). This paper provides a bridge between many different aspects of Rob's research and also provides an outstanding summary of the role of economics in managing environmental and resource issues over the last century. In particular, he highlights that the problem of the commons is not that the property is held in common per se, but rather that these resources suffer from a particular type of property rights failure, namely open access. He ties this insight to many environmental and resource issues ranging from land use, to fisheries, to the ultimate commons problem, global climate change.

3.2 Economics of Instrument Choice

When Rob received the call from Senator Wirth to lead up what became known as Project 88, he had not yet written a single article on the economics of instrument choice. Yet, his subsequent academic research, directly motivated by the policy work for Project 88, is arguably among his best-known, particularly among economists outside of the field of environmental economics and certainly in the policy world and public sphere. There are three major insights from this extensive body of research. The first

is that while market-based instruments have enormous promise, the details of how these policy instruments are constructed and used matter and each application will require a tailored approach. The second insight concerns the impacts of market-based instruments on the dynamic aspects of technological change and the inherent superiority of market-based instruments to traditional command-and-control standards on this front. The final insight reflects a more positive (as opposed to normative) understanding of how and when market-based instruments are likely to be selected in the policy process and successful in implementation. This section covers Rob's contribution along each of these dimensions.

In theory, market-based instruments lead to the cost-effective allocation of pollution abatement—firms with lower costs abate more and firms with higher costs abate less. But market-based instruments may have other costs, including monitoring and compliance costs that outweigh the cost savings. In a paper with Richard Newell, Rob developed a closed-form expression of the expected savings from using a market-based approach as a function of different measures of heterogeneity in abatement costs and showed how this formula can be used to estimate cost savings for regulation of nitrous oxides (Newell and Stavins 2003).

One of the key arguments for tradeable permits is that they can yield the same cost-effective outcome as pollution taxes (they both achieve a given level of pollution reduction at lowest cost), but may be more politically viable. One of the features that may make tradeable permits more politically appealing is that you can give the initial permits away at no cost and the ultimate allocation of pollution responsibility, after trade, is invariant to the initial allocation. Both of these features of tradeable permit systems—the parity with pollution taxes and the invariance to initial permit distribution—are oft-cited (dating back to Montgomery 1972) and taught in every undergraduate environmental economics course. They are also incorrect. One way in which they are incorrect is that these findings do not account for transaction costs, a finding Rob brought to light in his paper, "Transaction Costs and Tradeable Permits", published in the *Journal of Environmental Economics and Management* (Stavins 1995). The key insight from this paper is that finding trading partners, especially in thin markets (where there are few polluters), involves transaction costs. These costs reduce trading levels and thus increase abatement costs above the cost-effective minimum achieved by a pollution tax. Moreover, in some reasonable situations (with certain transaction cost functions and certain initial distributions of permits), the ultimate distribution of abatement after trading is sensitive to the initial allocation of permits. How much these transaction costs matter is a function of how the market

is constructed and, hence, the details matter in choosing between a permit system and a pollution tax.

Rob further explored the role of initial allocation in a cap-and-trade system in a paper with Robert Hahn called "The Effect of Allowance Allocations on Cap-and-Trade System Performance" (Hahn and Stavins 2011). In this paper they show that there are many reasonable conditions under which the initial allocation of permits can lead to different equilibrium allocations of abatement responsibility, including transaction costs, market power in the permit market, uncertainty about future allowance prices and certain regulatory features of the cap-and-trade system. Despite many reasons why the initial allocation may matter, their empirical analysis of existing cap-and-trade programmes did not find evidence of the types of problems and conditions that would lead to concerns about the initial allocation. In practice, at least for systems in place at that time, initial allocation appeared to be largely independent of the ultimate equilibrium outcome.

Another way in which permit systems and taxes can lead to different outcomes stems from uncertainty, a point made in a critical paper by Martin Weitzman, fellow Harvard environmental economist. In "Prices vs Quantities" (Weitzman 1974), Marty demonstrated that uncertainty in marginal abatement costs makes price instruments (such as a pollution tax) more efficient when the marginal costs of pollution abatement are steeper than the marginal benefits, while the quantity instrument (such as a tradeable permit system) is more efficient when the marginal benefits are steeper than the marginal costs. In that paper, Weitzman also shows that uncertainty in marginal benefits does not affect the relative efficiency of the two instruments. In a footnote, Weitzman pointed out that if there is correlation in uncertainty between marginal costs and uncertainty in marginal benefits, then the uncertainty in marginal benefits could affect the relative efficiency of the two instruments. But this point was largely lost and the takeaway from Weitzman (1974) was usually that uncertainty in marginal benefits does not affect the choice of instrument. In "Correlated Uncertainty and Policy Instrument Choice", published in the *Journal of Environmental Economics and Management* (Stavins 1996), Rob demonstrated that correlations in uncertainty between marginal costs and marginal benefits are not unusual. This means that uncertainty over marginal benefits can matter. But more importantly, Rob demonstrated that for reasonable parameter specifications, this correlated uncertainty can lead to the opposite relative efficiency of price and quantity instruments from what Weitzman (1974) found. That is, under reasonable levels of correlation, the price instrument could be relatively more efficient when marginal benefits are steeper than marginal costs while

the quantity instrument could be relatively more efficient when marginal costs are steeper than marginal benefits. Yet again, Rob's work shows that the details matter in deciding between the two market-based approaches to environmental policy.

One interesting empirical reality is that many environmental problems are not addressed by a single policy instrument, but rather by a combination of different policy instruments. Rob and I looked at the use of multiple policy instruments in three domains, energy efficiency, toxic chemical control and fisheries management, and explored the circumstances under which the use of multiple policy instruments might be justified on economic grounds (Bennear and Stavins 2007). When there are multiple market failures or there is an exogenous external constraint, the use of multiple policy instruments may be economically justified, yet we note there is little research to support the use of the actual combinations of instruments observed.

While the prior papers focus on the economics of choice among market-based instruments, for most policy discussions the choice being considered is between a market-based instrument and a more traditional (command-and-control) instrument. Economists have long argued for market-based instruments because they are cost-effective—they achieve a given level of pollution reduction at lowest cost (see, for example, Tietenberg 1990). That is a static analysis that takes abatement costs as fixed. However, there is also a dynamic argument for market-based instruments, namely that they induce greater levels of technological change because they reward decreases in marginal abatement costs (either firms pay less in pollution taxes or firms free up permits they can sell on the market). Rob teamed up with one of his graduate school advisers, Adam Jaffe, and empirically estimated the effects of different policy instruments on the rate of technological change. In particular, they look at one aspect of technological change, the diffusion of a new, but commercially available, technology (Jaffe and Stavins 1995). Their application is in energy efficiency of new housing and they examine three different policy instruments—an energy tax, an energy-efficiency subsidy and direct regulation through building standards. They find that the subsidy has the largest impact followed by taxes. Their analysis revealed that the technology standards in building codes had no measurable impact on energy efficiency, although they point out these standards may have been set below what was already in common practice. That finding, that standards may be set below what is already available on the market, is itself evidence of the superiority of market-based instruments in providing incentives for technological change—they continue to provide incentives on the margin while technology standards

can have no effect if they are set too low or, alternatively, can have effects only until the standard is achieved and then the incentive is eliminated.

Rob's initial foray into the economics of instrument choice was in his service on Project 88, a project that eventually resulted in the implementation of a tradeable permit system for sulfur dioxide as part of the Clean Air Act Amendments of 1990. Naturally, as an intellectual architect of this programme Rob has been frequently called upon to reflect on the experience and the lessons learned. One such reflection can be found in his paper "What Can We Learn From the Grand Policy Experiment? Lessons from SO_2 Allowance Trading", in the *Journal of Economic Perspectives* (Stavins 1998). In this paper, Rob considers the positive (as opposed to normative) reasons why a tradeable permit system was able to succeed in the late 1980s when it had limited success previously. These reasons included: the increase in pollution control costs which made cost savings from market-based instruments more important; vocal support for the approach from one of the major environmental groups, the EDF; the fact that the programme was designed to significantly reduce emissions and not just lower costs; the fact that economists working on this policy issue were willing to put aside the question of efficiency and focus solely on cost-effectiveness; and finally, sulfur dioxide was largely unregulated so there were few status quo biases at play. Rob also identified normative lessons from this experiment in market-based environmental policy, including that: systems should be designed to allow for the broadest set of compliance alternatives (e.g. allow trading but also banking and borrowing of permits); systems should use a simple approach to allocating permits that cannot be manipulated and have simple trading rules that are defined upfront; trading systems are best suited to cases where enforcement is easy and low-cost; and that the private sector can make these markets work by establishing brokerages to facilitate trade.

In follow-up work with Richard Schmalensee, Rob takes a wider historical view at this policy experiment and highlights four ironies of its perceived success (Schmalensee and Stavins 2013). They find that while Congress acted to curb sulfur dioxide emissions to reduce acid rain, the bulk of the benefits of the programme are local health benefits from reductions in small particulate matter, leading them to argue that Congress did the right thing but for the wrong reason. The second irony is that most of the cost savings from the programme came not from trading per se, but from railroad deregulation which enabled Midwest power plants to more cheaply switch from high-sulfur Appalachian coal to low-sulfur coal from the Powder River Basin in Wyoming. The third irony is that while the cap-and-trade programme was a policy victory for a Republican administration, market-based programmes

have come to be vilified by the Republican Party. The final irony is that subsequent court decisions and regulations led to the collapse of the sulfur dioxide trading programme, thus bringing the grand policy experiment to an unfitting end.

In "The Choice of Regulatory Instruments in Environmental Policy", Rob and co-authors Nathaniel Keohane and Richard Revesz continue to explore the positive dimensions of policy instrument choice (Keohane et al. 1998). They examine four major deviations between real-world policy adoption and economic recommendations. First, command-and-control policies were far more frequently used than market-based instruments despite the economic evidence on the cost-effectiveness of market-based approaches. Second, command-and-control approaches were frequently weaker for existing facilities and more stringent for new facilities (sometimes called grandfathering) despite economic evidence of the inefficiency of such vintage-differentiated standards. Third, when market-based instruments are used the permits are almost always given away at no cost despite economic recommendations to auction them or to use a price instrument such as a tax. Finally, they noted that the political appeal of market-based instruments had risen significantly over time. In their paper they develop an equilibrium framework that explains these gaps by combining political factors on the supply side with economic factors on the demand side.

One of the insights from the prior paper was that standards may be preferred because they can be applied selectively only to new firms. This vintage-differentiated regulation may be politically appealing to lawmakers because they insulate existing firms in their district (and the voters that work for those firms) from more stringent regulation while enabling the legislator to vote for more tougher environmental policies. Rob explored the impacts of vintage-differentiated regulations in more detail in a paper published in the *Stanford Environmental Law Journal* (Stavins 2006). In this paper he provides the economic argument against such regulations because they slow capital turnover resulting in firms holding onto older, more polluting technology for a longer time. Ultimately, this leads to decreases in environmental protection and drives up costs.

3.3 Economics of Technological Change

The third theme in Rob's research focuses on the economics of technological change—particularly as it relates to environmental regulation. This theme

dates back to his graduate school days working with Jaffe and Griliches. Technological change can be broken down into three related, but distinct, components—invention, innovation and diffusion (Schumpeter 1939). Invention is development of a prototype device or process that solves a technical problem or improves upon the performance of prior devices/processes. Innovation is taking that protype and making it commercially viable. Diffusion is the adoption of the new innovation over time.

One key question in this area of inquiry is why the diffusion of energy-saving technologies is slower than would appear justified based on the net present values of savings relative to installation costs—the so-called energy-efficiency paradox. While many have postulated behavioural explanations for the paradox, in "The Energy Paradox and the Diffusion of Conservation Technology", Rob and Jaffe discuss several neoclassical explanations for the paradox, including: information problems, unobserved costs, high discount rates and unobserved heterogeneity among adopters (Jaffe and Stavins 1994a). In a related paper these same co-authors examine what is meant by "optimality" in the case of diffusion of energy-efficient technologies and explore how these differences in definition of what is "optimal" explain the energy-efficiency gap (Jaffe and Stavins 1994b, c).

Rob extended the work with Jaffe and Newell to look at the effect of environmental policies on the innovation stage of technological change. In "The Induced Innovation Hypothesis and Energy-Saving Technological Change", they use data collected from the Sears Catalog from 1958 to 1993 on detailed product characteristics of durable appliances to examine the effect of changes in government regulations on the energy efficiency of those appliances (Newell et al. 1999). They also examined the impact of exogenous factors such as changes in energy prices. They found little evidence that energy-efficiency standards had a significant impact on product characteristics. The rate of innovation was not affected by energy prices or regulation while the direction of change (towards more energy efficiency) was affected by energy prices but only for some products. Energy prices changed the menu of characteristics that were available for sale, and those changes were further accelerated by requirements for energy labelling on consumer durables.

Rob and his co-authors continued to publish extensively on this topic. In "A Tale of Two Market Failures: Technology and Environmental Policy", they investigate how market failures in the form of pollution externalities interact with market failures on the technology side such as adoption spillovers (Jaffe et al. 2005). While no single policy has proven to dominate in terms of simultaneously addressing these two market failures, the authors advocate for broad policy experimentation with detailed evaluation to determine what works

best. The three co-authors have also published several survey and review articles on this topic (Jaffe et al. 2002, 2003; Newell et al. 2006).

Rob and I collaborated with Nolan Miller on a paper that examined the impact of both economic and regulatory changes on technology diffusion in the chlorine manufacturing industry (Snyder et al. 2003). We found that environmental regulation did affect the overall technological mix in the industry, not by increasing adoption of cleaner technology at existing plants but by reducing demand for chlorine and accelerating the closure of facilities using older technologies.

3.4 Natural Resource Economics and Land-Use Change

Rob's dissertation research (described briefly in Section 2) examined the impact of federal investment decisions, particularly flood protection decisions along the Mississippi River, on wetlands depletion. This work was published in a co-authored paper with Jaffe (Stavins and Jaffe 1990) and was important for two reasons. First, the findings are key to understanding the impact of public investment decisions on the behaviour of private landowners. They find that 30% of wetlands depletion along the Mississippi is the result of private decisions among landowners that were induced by federal flood control projects. Second, they developed an important econometric method for situations where the model focuses on individual behaviour (of households, landowners or firms), but the available data are aggregated across individuals (e.g. county level or zip code level). Their method allows for joint estimation of the individual parameters of theoretic interest along with a functional relationship that captures the unobserved heterogeneity in the distribution of individual data at the level of data aggregation. This method has broad application outside of environmental and resource economics.

A second paper from Rob's dissertation develops a model for estimating the socially efficient level of wetlands (or other natural resources) when there are negative externalities (Stavins 1990). This model is then used to simulate the efficient level of forested wetlands in the Mississippi River area from 1935 to 1984. To estimate the socially efficient level of forested wetlands, one needs estimates of the ecological benefits of wetlands which include flood protection, water quality improvements and species habitat (and, in modern times, carbon sequestration to mitigate climate change). The values of these ecological benefits then represent the negative externalities associated with wetlands depletion. This study finds that for reasonable ecological values provided by wetlands, zero net loss of forested wetland would have been justifiable over this period.

Rob continued to work periodically on natural resources issues, frequently with PhD students. One such student was Sheila Olmstead, who was interested in the economics of water resources. As part of her dissertation she co-authored with Rob and Michael Hanemman of the University of California, Berkeley, a paper that evaluated the impact of block-rate pricing on water use. Using detailed household-level water data, they estimated a structural model for the price elasticity of demand that accounts for the block structure and its piecewise impacts on the budget constraint (Olmstead et al. 2007). They also examined whether the price structure itself affected water use, aside from the price levels. In other words, do households facing increasing block prices respond to the block structure rather than the actual level of prices associated with each block? They do find some evidence of block structure affecting price elasticities, but given the possible endogeneity of price structures they cannot rule out that these differences are due to unobserved heterogeneity at the water utility level.

In another paper with two PhD students, myself and Alex Wagner, Rob developed a method for estimating the economic benefits of a recreational fishing day—a commonly used measure of the value of lakes and streams (Snyder et al. 2005). This method estimated the value of a fishing day by estimating the demand for fishing licenses, which provide an option to use an open-access natural resource. Previous methods for estimating the value of a fishing day, which include inferring values based on the opportunity cost of travelling and using a site for recreation (travel cost models) or analysis of survey data (stated-preference methods), provide estimates that are site-specific and not directly comparable. In contrast, this method provides estimates that can be compared across different geographic areas and, indeed, we find significant variation in the value of a recreational fishing day across the US.

In addition to a passion for environmental economics, Rob is also a connoisseur of wine. His professional interest in resource economics and personal interests in wine intersected in a co-authored paper with Robin Cross and Andrew Plantinga that examines the return on *terroir*, or the special characteristics of the place in which grapes are grown and harvested, to wine values in the US (Cross et al. 2011). They used data from vineyard sales in the Willamette Valley, Oregon, to conduct a hedonic property study to distinguish between two concepts: the "reality of terroir" which would vary based on actual soil, climate and geological conditions and the "concept of terroir" which reflects the location of the vineyard within an officially named appellation. They found that vineyard prices are determined by the location

of the vineyard within the appellation (concept of terroir), but not by the specific site characteristics (reality of terroir).

3.5 Economics of Climate Change

Rob has become one of the world's thought leaders on the issue of the economics of climate change. As you will see in this section, his research on climate change builds upon all the other previous strands of research, starting with his dissertation. The methods developed in Rob's dissertation for analysing land-use changes were incredibly relevant for studying the economic impacts of climate change. One of the key mitigation strategies for climate change, in addition to a reduction in greenhouse gas emissions, is raising carbon dioxide sequestration through increased forestation and reduced deforestation. In early policy debates, particularly around the time of the negotiations over what became the Kyoto Protocol, the role of forests in climate change mitigation was highly contested. Some countries, such as the US, Canada and Australia wanted the international agreement to allow the use of carbon sequestration from reforestation and reduced deforestation to count as "offsets" for carbon dioxide emissions, while other countries, most notably those in the European Union, wanted to focus solely on reductions in emissions. Part of the debate on the role of offsets was philosophical, but part of it hinged on uncertainty over the marginal costs of climate mitigation through carbon sequestration. Rob extended his dissertation research to estimate the costs of carbon sequestration in a 1999 paper in the *American Economic Review* called "The Costs of Carbon Sequestration: A Revealed-Preference Approach" (Stavins 1999). In this paper he found that the costs of carbon sequestration in forests were highly non-linear and generally much higher than previously anticipated. The results indicate that reforestation and reduced deforestation might play a smaller role than anticipated in the long-run strategy to mitigate climate change.

Rob's continued work on estimating the costs of carbon sequestration continued with a 2006 article co-authored with Ruben Lubowski and Andrew Plantinga called "Land-Use Change and Carbon Sinks: Econometric the Carbon Sequestration Supply Function" (Lubowski et al. 2006). This paper used detailed land use and land quality data from across the US and modelled landowners' choices among six different land-use options. Land-use choices were modelled as a function of profitability in the various uses and commodity prices were treated as endogenous. They find that the marginal costs of carbon sequestration are roughly on a par with the costs of

other forms of climate mitigation, specifically reductions in greenhouse gas emissions and thus should be an option in climate negotiations.

As mentioned in the biography, Rob continued and expanded his policy engagement on climate change by serving as a lead author on the Working Group III (Socioeconomics) of the Second Assessment Report of the IPCC. In a similar pattern to what occurred following Rob's work with Project 88, his work with the IPCC formed the basis for much of his scholarship on the economics of climate change. His work with the IPCC was captured in a co-authored paper "An Economic Assessment of Policy Instruments for Combatting Climate Change" (Fisher et al. 1996). This was the beginning of a series of papers exploring policy instrument choice for climate change. In "Policy Instruments for Climate Change: How Can National Governments Address a Global Problem?", Rob demonstrates the advantages of market-based instruments for climate change and argues for a cap-and-trade system with freely allocated (or grandfathered) permits while recognising that a carbon tax, particularly a revenue-neutral carbon tax, could be preferable in the long run (Stavins 1997). This analysis contributed to what was a nascent, but rapidly growing literature (at that time), on the comparative advantages of cap-and-trade and carbon taxes, a debate that continues to be critically important. Further exploration of a domestic cap-and-trade system, this time with a combination of freely allocated and auctioned permits, can be found in Stavins (2008).

The Kyoto Protocol was the international agreement that resulted from complex geopolitical negotiations as part of the United Nations Framework Convention on Climate Change. The Protocol set a series of targets and timetables but only for developed countries. Developing countries could opt in to the targets and timetables or could participate through bilateral projects with developed countries in what was called the Clean Development Mechanism. Kyoto was widely criticised by economists both for the targets and timetables approach and for the lack of meaningful participation from developing countries—countries whose contribution to carbon emissions was expected to increase significantly. Given this widespread criticism, a reasonable question might be, how does the Kyoto Protocol compare to alternatives that could have been selected? Rob together with Joseph Aldy and Scott Barrett explore that question in their paper "Thirteen Plus One: A Comparison of Global Climate Policy Architectures" (Aldy et al. 2003). They compared 14 different policy approaches along six dimensions: how well does the policy attain the desired environmental outcome (effectiveness), dynamic efficiency (in the economic sense of maximising the present value of net benefits), cost-effectiveness, equity, flexibility in the presence of new

information, and incentives for participation and compliance. While they argue that the Kyoto Protocol does poorly along several of these dimensions, none of the other alternatives performed well on all six dimensions—there were always some trade-offs, particularly among effectiveness at attaining the desired environmental outcome and efficiency, and between cost-effectiveness and the incentives to participate and comply. Their comparative analysis revealed several shared weaknesses in the Kyoto Protocol relative to the alternatives. In particular, Kyoto tried to achieve "too little, too fast" relative to more cost-effective approaches that more gradually ramped up but to much more stringent mitigation targets. The Kyoto Protocol failed to secure participation of developing countries and that absence reduced the effectiveness and cost-effectiveness of the Protocol relative to alternatives. They also found that price-based instruments such as cap-and-trade or carbon taxes were consistently the most cost-effective and that most proposals focused too little attention on incentives for participation and compliance despite the critical importance of those issues in the ultimate success or failure of the policy.

As the compliance period for the Kyoto Protocol came and went, Rob's attention turned to what economics might bring to a post-Kyoto climate change policy architecture. His views were nicely summarised in a co-authored paper with Sheila Olmstead (Olmstead and Stavins 2006). The paper answers the who, when and how of the next generation of climate policy. In terms of who should be included, they argue that all countries, both developed and developing, must be included. On when, they argue that initial targets should be relatively low, but ratchet up over time. Finally, on how, they advocate for the use of market-based approaches but with national sovereignty over the choice of market-based approach.

The title of one of the prior papers, "How Can National Governments Address a Global Problem?", hints at a tension that had only really begun to surface in policy debates at that time, namely that if global agreements to solve a global commons problem would rely on national governments to make policy choices and implement those choices, then there could be issues in linking these different national policies and potentially unintended interactions among different national policies. Rob wrote a paper with Robert Hahn that examined the interaction of a global trading system, which was the proposed policy under the Kyoto Protocol, with myriad and diverse domestic policy instrument choices (Hahn and Stavins 1999). They demonstrate that the cost-effectiveness of a cap-and-trade approach to climate change can be significantly reduced by a reliance on national policy choice and implementation. While the Kyoto Protocol preserved national sovereignty in climate

policy, it did so at the expense, and potentially large expense, of reductions in cost-effectiveness.

Rob worked with Matthew Ranson and Judson Jaffe on several papers that examine issues in linking across different national trading programmes. One prominent example is their 2009 paper "Linking Tradable Permit Systems: A Key Element of Emerging International Climate Policy Architecture" (Jaffe et al. 2009). Linking different domestic permit and credit systems has some clear economic advantages, including that it lowers compliance costs as firms can now trade across national boundaries, it can increase market liquidity and reduce concerns about market power and it can reduce price volatility. But there are also some concerns about linking different domestic trading programmes such as potential "double counting" and the need to ensure additionality, distributional concerns about the location of emissions reductions (which may not matter for carbon dioxide but matters for co-pollutants with local health effects), a reduction of domestic control over climate policy, and changes to the incentives domestic governments face when setting compliance targets. They also focus on three potential roles that linkage could play in the long-term climate architecture: linkages serving as a bottom-up approach to a comprehensive global trading architecture; linkages serving as "proof of concept" motivating the development of a top-down global trading architecture; and linkages that remain one component of a different global climate architecture.

Issues involving interactions of different national policies also arise among interactions of subnational (state-level) and federal policies in the US, which Rob explored with co-author Lawrence Goulder in "In Challenges from State-Federal Interactions in US Climate Change Policy" (Goulder and Stavins 2011). They demonstrate how state policies that are more stringent than federal policies (or exist in the absence of federal policies) can result in emissions leakage—emissions reductions in the more heavily regulated state are offset by increases in emissions in the less regulated state. This is true for clean energy/energy-efficiency standards and for fuel economy standards for motor vehicles. The same paper also shows that similar issues do not arise if price-based policy approaches are used.

Rob continues his policy engagement with respect to climate change. He writes a popular blog on climate policy and also runs a podcast on this topic.

4 Conclusion

Robert Stavins' research and policy engagement has shaped a generation of environmental policies both in the US and abroad. His research spans several related areas, including the economics of policy instrument choice, the effect of environmental policy on technological change, the economics of natural resource management, and climate change. In each area, his research is tied to important policy questions, most notably the defining environmental problem of our time, climate change. But critically he does not just publish academic articles that can inform policy debates. Rather, he is an active participant in policy processes, from Project 88 which formed the basis of a movement towards market-based approaches to environmental policy, to serving on the Scientific Advisory Board of the US EPA, to serving as an author and lead author on the IPCC. Such connected and policy-engaged research is the hallmark of the Harvard Kennedy School and Rob has become one of its most prominent thought leaders.

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