TECHNOLOGICAL INNOVATION THROUGH ENVIRONMENTAL POLICY

California's Zero-Emission Vehicle Regulation

MARK B. BROWN
Rutgers University
WEERT CANZLER
Wissenschaftszentrum Berlin für Sozialforschung (WZB)
FRANK FISCHER
Rutgers University
ANDREAS KNIE
Wissenschaftszentrum Berlin für Sozialforschung (WZB)

State and federal governments have been involved in the regulation of automotive air pollution since the mid-1960s. Legislation of the 1970s usually took a "command and control" or "technology-forcing" approach to reducing mobile source (motor vehicle) emissions. Lawmakers set high standards for air quality and threatened industry with fines if it did not develop the technology needed to meet the standards. During the 1980s environmental regulation of industry, always a controversial issue, came under increased attack as an apparent constraint on technological innovation and economic growth. Proponents of deregulation argued that the "free market" rather than government regulation provides both the most effective and efficient supply of pollution-reducing technologies. Interestingly, many environmentalists have not rejected the view that government command regulation constrains technological innovation. Rather, they claim that constraining innovation is the necessary price of environmental protection. Many environmentalists and free-market advocates thus share the conviction that environmental protection and technological innovation operate against each other.

This conviction is being challenged by recent mobile source regulation in California. The 1990 Low-Emission Vehicle and Clean Fuels (LEV) regulatory program, with its zero-emission vehicle (ZEV) mandate, serves both environmental protection and technoindustrial policy goals. Further, the program uses both command regulation and market-oriented tools. This combination of regulatory tools and goals can be called an ecoindustrial model of environmental regulation. To be sure, the LEV/ZEV regulatory

Public Productivity & Management Review, Vol. 19 No. 1, September 1995 77-93

program is not the first program to combine ecological protection and industrial goals. In this respect, the strategy might be compared with the recently much used—and some would say "abused"—notion of sustainable development. The following discussion draws on a growing body of policy literature, both academic and practical, that similarly attempts to reconcile environmental protection and technological innovation (see, e.g., Heaton, Repetto, & Sobin, 1992; Moore & Miller, 1994; Porter, 1990; U.S. Office of Technology Assessment, 1992).

This article examines the strengths and limitations of ecoindustrial regulation, and provides an overview of the public debate surrounding the ZEV mandate. Although ZEVs are defined as any vehicle producing no emissions from the vehicle itself, public debate of the ZEV mandate has focused on electric vehicles (EVs) as the most feasible zero-emission option. Although the potentials of electric vehicles do not affect the viability of the ecoindustrial model as such, they stand at the center of the California program's strategy.

Although it is too soon to assess the program's overall economic impact, the ZEV mandate has already been successful in stimulating the emergence of a regional (perhaps global) market in environmentally critical transportation technologies, particularly electric vehicles. The ZEV mandate thus provides a useful case for discussing the ecoindustrial model. Before moving to an examination of the mandate, however, it will be helpful to briefly assess the recent history of the relevant policy areas in light of the above issues.

Thirty Years of Command and Control Regulation

In 1960, in the absence of serious federal attention to automotive air pollution, the California legislature passed the world's first automobile emissions control legislation: the Motor Vehicle Pollution Control Act. As studies began to show that pollution was being transported across state boundaries, the need for federal involvement became compelling. The auto industry also supported federal standards as far preferable to the confusing array of design requirements posed by the 18 different auto emissions control bills introduced in state legislatures by 1967 (Krier & Ursin, 1977; Robertson & Judd, 1989, p. 334).

Throughout the 1970s, federal environmental regulation was characterized by frequent federal preemption of state authority and highly ambitious goals that ignored economic or technological feasibility (John, 1994). The 1970 Clean Air Act amendments required state and local air pollution agencies to achieve a 90% reduction in automotive hydrocarbon and carbon monoxide emissions by 1975 and a 90% reduction in nitrogen oxide emissions by 1976. Congress set these standards solely according to human health requirements, attempting to force industry to develop the necessary technology. The 1970 legislation also explicitly encouraged states to make use of social innovations to reduce automotive air pollution through nontechnical means (e.g., increased mass transit, reduced parking subsidies, gasoline rationing). But the inability of state governments to stand up to the pressure of automakers and (to a lesser extent) angry consumers led to an emphasis on the less controversial approach of pushing automakers to develop and use new technological devices to reduce emissions (Krier

& Ursin, 1977, chap. 12). Referred to as "technology forcing," the practice failed to compel automakers to meet a single one of the deadlines. In each case the auto industry sought and received either waivers or extensions.

The technology-forcing or command bias that evolved during the implementation of the 1970 Clean Air Act made government agencies particularly vulnerable to auto industry delay tactics. During the "energy crisis" of the early 1970s, for example, the auto industry made use of the new public concern over fuel economy to argue for further delays in emissions standards, claiming that the available technology did not allow simultaneous improvements in both areas. This contributed to passage of the Energy Policy and Conservation Act in 1975, establishing the Corporate Average Fuel Economy (CAFE) standards. These standards also took a technology-forcing approach (Knie, 1994, pp. 182-186; Krier & Ursin, 1977, pp. 234-238).

As industry continually failed to meet rigorous legislative goals without serious sanction, automakers quickly developed a strong disdain for the Environmental Protection Agency (EPA) and its regulations (Sagoff, 1988, pp. 197-202). Over the years, automakers and others have raised a number of important objections to the technology-forcing or command approach. First, in attempting to monitor compliance with hundreds of environmental regulations at thousands of facilities, command regulation has led to huge, ineffective bureaucracies. Second, although command regulation is sometimes appropriate for stationary, single-point pollution sources such as power plants or factories, nonpoint sources such as agricultural fertilizers or automobiles are too dispersed to be effectively monitored by government regulators (John, 1994). Third, rather than forcing innovation, command regulation has sometimes inhibited innovation because it gives producers no incentive to go beyond the requirements of a specific regulation. Fourth, command regulation actually gives producers the incentive to conceal any innovative environmental protection measures for fear that their new measure will become required by a new regulation (Sagoff, 1988, p. 206). Finally, command regulation can contribute to "agency capture," because the standards set are often based on information provided largely by the same firms who will eventually be required to comply with them (Heaton, 1990, p. 7).

Achievements of Command Regulation

As one might expect from the above summary, the measurable impact of command regulation on automotive emissions and air quality has been mixed at best. The most clear-cut success in motor vehicle pollution control has been in the area of lead emissions. In 1974 the EPA adopted a timetable to reduce the level of lead in gasoline. In the United States, lead emissions fell by 96% between 1970 and 1987. As a result the average lead level in Americans' blood dropped by more than one third between 1976 and 1980 (Weisskopf, 1987). Reductions in motor vehicle emissions through the use of catalytic converters have been far less decisive. After years of opposing emissions control legislation, the auto industry presented this "end-of-pipe" technology as its regulatory option of choice because it did not require any fundamental changes in automotive design. The National Academy of Science characterized this

approach as "the most disadvantageous with respect to first cost, fuel economy, maintainability, and durability" (Adams & Brock, 1990, p. 120). Indeed, although 60% of a car's pollutants are given off in the first few minutes of a typical trip, before the engine warms up, catalytic converters only work effectively once the engine has reached a temperature of 700°F (Nadis & MacKenzie, 1993, p. 57). Recent developments in electrically heated catalysts may eventually provide a solution to this problem. Currently available converters also lose their effectiveness at high speeds and after approximately 50,000 miles of use. Finally, they are prone to tampering by drivers seeking to increase their car's performance. Nevertheless, the worldwide introduction of the catalytic converter has reduced conventional emissions of carbon monoxide, hydrocarbons, and nitrogen oxides from individual motor vehicles by up to 90% over the (highly polluting) 1972 model year (Nadis & MacKenzie, 1993, p. 22).

Further improvements of the internal combustion engine—new materials, modern measuring and regulating technologies, optimization of combustion chamber geometry—have also allowed an increase in fuel economy. In addition to the 1975 CAFE standards for fuel economy, 1978 legislation imposed a "gas guzzler" tax on inefficient cars. Perhaps more significantly, the U.S. Big Three automakers faced increasing competition from fuel efficient foreign models appearing on the U.S. market in the 1970s. Indeed, as *Fortune* magazine has pointed out, without the imposition of fuel economy standards by the government, U.S. automakers might have been even more surprised than they were by the shift in consumer preferences toward small cars (Adams & Brock, 1990, p. 121). The average fuel economy of new U.S. passenger cars increased from 15.7 miles per gallon (mpg) in 1975 to 27.8 mpg in 1991 (International Energy Agency, 1993, p. 71).

Remaining Challenges

Despite the auto industry's frequent claims to the contrary, these considerable technological improvements have not been able to eliminate the pollution problems of the automobile. The emissions reductions achieved through improvements in conventional vehicle technology have been largely overwhelmed by increases in the number of cars on the road and the total miles driven. Between 1950 and 1990 the number of passenger vehicles in use worldwide rose from 50 million to over 450 million. In the United States, the yearly vehicle miles traveled increased from 750 billion to 2000 billion. Thus, despite the substantially decreased emissions of individual vehicles in the United States, total motor vehicle emissions of volatile organic compounds and carbon monoxide decreased by less than 50% between 1970 and 1988. Total nitrogen oxides emissions were reduced by less than 25% between their peak in 1981 and 1988 (Bryner, 1993, p. 133). Motor vehicle CO_2 emissions—which are not affected by catalytic converters—increased by over two thirds in the United States over the last 2 decades. Between 1988 and 1992, as Americans returned to larger cars, average fuel economy dropped by 4% (Nadis & MacKenzie, 1993, pp. 31, 18).

The highly publicized "intelligent vehicle highway systems"—efforts to improve traffic flow with electronic sensing and information technology—do nothing to counteract this trend. Repeated attempts to reduce driving by increasing the U.S.

gasoline tax—currently about four times lower than that of many other industrialized countries—have failed to acquire sufficient political support. Public transit remains a viable option only in selected densely populated cities, and in most cases still fails to capture a significant portion of the total miles traveled.

For decades now both environmentalists and automakers have also sought solutions in various alternative engine designs. The auto industry has directed significant efforts toward developing electric vehicles, as well as alternative systems such as the Stirling motor, the gas turbine, or the rotary motor produced by NSU/Wankel and Mazda. With the exception of certain pilot projects or test fleets, however, all major automobile manufacturers have remained committed to the internal combustion engine. Although substantial successes can be recorded in certain areas—the reduction of lead emissions or improved fuel economy—automakers, consumers, and federal environmental regulators have not seriously pursued the introduction of alternative transportation technologies that go beyond the conventional automobile (Knie, 1994).

The Free Market Versus Command Regulations

Industry's disdain of environmental regulation was to emerge in the mid-1970s as a call for "deregulation." A call for the return to free market mechanisms, deregulation of environmental protection became an explicit objective of the Reagan administration in the 1980s. Since then, environmental command regulations have faced increased opposition from advocates of a "free market environmentalism." Arguing that environmental regulation constrains technological innovation, free market advocates seek to greatly reduce government involvement in pollution control. Such deregulation leaves industry to reduce pollution solely according to short-term market signals. It is an approach that has generated much heated debate. Despite the failures of the command approach, most environmentalists argue that altogether replacing the command approach with the market mechanism would seriously weaken environmental protection.

In this respect, some have begun to see advantages in an approach that would combine elements of both approaches. One partial step in this direction was the 1990 Clean Air Act.

After a decade-long environmental stalemate in Congress, the Clean Air Act of 1990 was introduced and signed into law by President Bush. Much of the 1990 act continued to make use of a command approach. It established, for example, five new categories of federal standards for urban ozone levels. More importantly, however, the act introduced market-oriented measures. To reduce stationary source air pollution, for example, the act has sought to create regional markets for "emissions credits." These credits are auctioned to coal-fired electric power plants and other major pollution sources, and then bought and sold among the plants themselves. Sources with low control costs have an incentive to reduce their emissions and sell their credits to those plants with higher marginal control costs, resulting in the most economically efficient pollution reduction (Bryner, 1993, pp. 123-130). California's Low-Emissions Vehicle Program and its zero-emission mandate similarly use a market-oriented credit-trading scheme, but specifically integrates it with traditional commands. The remainder of this article is devoted to a more detailed assessment of this policy innovation.

Ecoindustrial Regulation: Integrating Command and Market Approaches

Many experts argue that further progress in reducing the social and environmental costs of auto-centered mobility will require a strategy that combines the four following ecoindustrial regulatory components: (a) regulatory commands, (b) market incentives, (c) environmental protection, and (d) technological innovation. It is a model that explicitly challenges those policymakers, economists, and industrial representatives who maintain that environmental regulations limit technological development. For example, according to World Resources Institute consultant George R. Heaton, Jr. (1990),

> First, it is necessary for policy-makers to make technological change the central means to accomplish long-term environmental sustainability. Second, public policies and practices in industry must be constructed so that environmental goals become essential, endogenous and natural to the progress of commercial technology. (p. 3)

A U.S. Office of Technology Assessment (1992) report similarly echoes this assessment, calling new product design both a "critical determinant of a manufacturer's competitiveness" and "a unique point of leverage from which to address environmental problems" (p. 3).

In an effort to incorporate environmental protection into government technology programs, various U.S. government agencies have recently included a category for "environmental technology" on their lists of economically and strategically critical technologies (Council on Competitiveness, 1991). The defense department has established an Environmental Security Technology Certification Program and a National Environmental Technology Test Site Program. The World Resources Institute also recently published a report identifying a variety of technologies not usually considered "environmental" technologies, but which have critical applications in environmental protection (Heaton et al., 1992). These include data collection technologies, superconducting technology, biodegradable polymers, and others (many relevant for electric vehicles). Addressing these technologies in their specific capacity for environmental protection promotes the identification of new opportunities for their development. The report also recommends a number of government policy options available for promoting these technologies. These include new patterns of R&D cooperation between government and industry, such as the Los Angeles consortia discussed below.

Aside from the environmental benefits, several observers have argued that the United States needs to move forward in environmental technologies simply for purposes of international economic competitiveness (Moore & Miller, 1994). Germany and Japan have had considerable success in using a combination of command regulations and market incentives to stimulate the innovation and subsequent export of environmentally critical technologies. Given the interconnectedness of world markets and the increasing consumer demand for environmentally sound products, progress in environmental technology promises international competitive advantage. Whereas German energy providers, for example, used to import emissions filter devices from Japan, Germany's stringent air pollution regulations have led the country to become the world's second largest exporter of such devices. Similarly, Germany's

"take back" requirements have compelled automakers and producers of other durable goods to take responsibility for final disposal of their products. German automakers have responded with important changes in automobile design to facilitate disassembly and recycling. General Motors has also announced plans to design cars meeting the German requirements. By the same token, every major automaker in the world is racing to develop technology meeting the California ZEV mandate.

In the past, one should note, environmental regulation has both retarded and stimulated technological innovation. Which of the two occurs is often difficult to assess and depends on the details of regulatory design and implementation. Only a few critical factors can be indicated here, each of which points to the importance of incorporating market-oriented measures into technology-forcing programs. First, stimulating technological innovation through regulation depends on giving industry sufficient time to develop new technology to meet the regulatory requirements. Second, successful development of environmentally sound technologies depends on a gradual and predictable enforcement of the regulation. If companies expect changes or delays in environmental regulations, they will be reluctant to invest heavily in new technologies for fear that they will not meet the future requirements. Third, successful ecoindustrial regulation depends on ensuring that the necessary infrastructure is in place to make the required environmentally sound technology profitable for industry. Firms require dependable consumer markets, supplier networks, and qualified workers before they will invest in new technology development (Hamrin, 1981, p. 61; Heaton et al., 1992; Vavonese, 1994).

The California 1990 Low-Emission Vehicle and Clean Fuels program meets all of these criteria for effective regulatory stimulus of environmental technology. It points to an innovative type of environmental and industrial policy. As the above considerations indicate, automakers have huge financial, institutional, and even psychological investments in conventional vehicle technology (Knie, 1994). Carefully designed government mandates can help companies overcome these barriers to innovation. To more clearly understand how the ZEV regulatory mandate has been applied in California, however, it is helpful first to explain why the program originated in that state.

California's Leadership in Mobile Source Regulation

California's widely acknowledged environmental policy leadership results from several factors, most obviously as a response to the severity of its problems. California's Los Angeles Basin is the only region in the United States classified as having "extreme" air pollution by the EPA. Of the 20 worst air quality regions in the United States, 9 are in California. Motor vehicles represent a logical focus for California's air pollution regulation, as cars and trucks in the Los Angeles area account for 70% to 80% of the region's air pollution. The South Coast Air Quality Management District estimates that air pollution in Southern California causes health, agricultural, and environmental costs of more than $7.4 billion annually (Lange, 1993, p. 71). The number of cars in the Los Angeles Basin is expected to increase by as much as 31% between 1987 and 2010. This means that pollution per mile driven has to drop by 60% just to stay even with 1987 pollution levels (Hall, 1993, p. 40).

Many other states, however, also have severe air pollution problems. In addition to the high level of environmental pollution, California's environmental policy leadership is in large part explained by the administrative capacity of the state's environmental bureaucracy. This factor has been instrumental to the success of the ZEV mandate. The California Air Resources Board (CARB), which implements the LEV/ZEV program, is the most capable air quality regulatory agency in the United States. Fiscally, CARB is relatively independent of both the federal government and other California state agencies. Compared to other states, California receives the lowest percentage of its environmental protection budget from federal grants. Additionally, in contrast to other California agencies, CARB's $103 million budget (1992) is largely insulated from political contingencies because it comes not from the state's general fund but from a variety of user's fees such as pollution permits and smog check certificates. When a budget crisis, for example, forced the administration to pay other state workers with IOUs for 2 months in the summer of 1992, CARB's 873-person staff got paid as usual (Wald, 1992). Managerially, CARB has a highly competent staff with an international reputation for technological and policy innovation. According to New York's environmental commissioner, CARB's mobile source program staff is more competent than the EPA's staff (Wald, 1992).

This financial and managerial capacity has provided CARB with considerable political autonomy in the face of interest group pressure. Former CARB chairwoman Jananne Sharpless reported that by November 1993 the auto industry had begun campaigning seriously to delay the ZEV mandate, and the state administration was under a great deal of pressure (Cone & Parrish, 1993). Auto industry representatives also voiced strong opposition to the regulation at the second biennial public review of the regulation in May 1994 in Los Angeles. After hearing over 24 hours of testimony, however, CARB refused to alter the regulation's timetable. This happened in spite of the fact that 7 of the 11 board members, including chairwoman Jacqueline Schafer, had been appointed within the past 2 years. This might have been expected to destabilize the board's political autonomy, but apparently did not.

As a result of this strong institutional capacity, coupled with the state's urgent need and the particularities of mobile source regulation, California has since 1967 been the only state allowed to obtain waivers from the federal EPA to promulgate its own air quality standards. Other states have the option to adopt California's standards if they can demonstrate their ability to implement and enforce them. California's strong state capacity has provided CARB the autonomy necessary for implementing an effective ecoindustrial policy.

The LEV Program and Its ZEV Mandate

The LEV/ZEV program and several government-industry partnerships in Southern California provide the basis for this new model of mobile source regulation. The program makes use of both technology-forcing and market-oriented approaches, and effectively links environmental and industrial policy. Moreover, because California's automotive air quality regulations have repeatedly been adopted by the United States EPA, and have often then appeared in similar form in other countries, the program has received wide national and international attention.

This regulatory program, adopted in September 1990 by the California Air Resources Board and approved in early 1993 by the EPA, regulates auto emissions at the point of sale according to four new vehicle classifications with increasingly stringent emissions standards: transitional low-emission vehicle (TLEV), low-emission vehicle (LEV), ultra-low emission vehicle (ULEV), and zero-emission vehicle (ZEV). The program requires a staged reduction of carbon monoxide, hydrocarbon, and nitrogen oxide emissions, and a first-time reduction of formaldehyde emissions. Significant for its overall strategy, the program allows new vehicles to be phased in over a 10-year period. As noted above, this type of gradual and predictable application of environmental regulations can help ensure that regulation accelerates rather than hinders technological development.

One should note that the first three low-emission vehicle categories depend on improving the traditional internal combustion engine. In addition to new fuels, emissions reductions are to be achieved with various on-board end-of-pipe technologies, such as improved catalytic converters. Given the limited possibilities for reducing pollution through the improvement of conventional engines or fuels, however, CARB also included a mandate for zero-emission vehicles.

The ZEV mandate requires that by 1998 a minimum of 2% of the vehicles offered for sale by major automakers in California emit no pollutants when driven—that is, electric vehicles. This number increases to 5% in 2001 and 10% in 2003. The mandate initially applies only to automakers selling over 35,000 vehicles per year in California, including Chrysler, Ford, General Motors, Honda, Nissan, Mazda, and Toyota. After 2003 the mandate also applies to companies selling a minimum of 3,000 vehicles per year. Small manufacturers selling less than this minimum are exempt. Automakers will be required to pay a $5,000 fine for each vehicle by which they fall short of their quota (California Air Resources Board [CARB], 1994; Woodruff, Armstrong, & Carey, 1994). It is possible that CARB will allow hybrid vehicles—which use both a small conventional engine and an electric motor—to count as ZEVs. So far, however, public debate concerning the mandate has focused on electric vehicles (EVs) as the zero-emission vehicle option most likely to appear in dealer showrooms by 1998.

Although the ZEV mandate is grounded in a traditional command approach to environmental regulation designed to force technological innovation, it also integrates market incentives that allow automakers unusual flexibility in meeting its strict standards. Automakers, for example, have the opportunity to fulfill their emissions reduction obligations during the entire period of the program by employing measurements of average emissions levels across an entire vehicle fleet rather than for each individual model. (The quotas for zero-emission vehicles, of course, must be met independently of the other low-emission categories.) Further, the program treats motor vehicles and the fuels needed to run them as a single system. This gives automakers the market flexibility to meet standards with the most efficient combination of measures affecting fuel content, vehicle design, or both.

The regulation also allows auto companies that exceed the regulatory requirements for any given year to accumulate LEV or ZEV credits. Like the emissions credits in the 1990 Clean Air Act, these credits can then be saved and applied to fulfill quotas in later years or sold to other companies. This lets automakers avoid investing in

expensive emissions reduction technologies for models where this imposes excessive costs or which are soon to be discontinued. In the case of ZEVs, it provides an incentive for small start-up companies to develop zero-emission vehicles to acquire ZEV credits, which they can sell to less innovative automakers. In sum, the regulation represents a radical departure from a pure command approach mandating uniform standards for mobile source emissions (Berg, 1991; CARB, 1994; Sperling, 1995).

Public Support for Electric Vehicles

Supporters of the mandate claim that electric vehicles promise significant pollution reductions in California and internationally. The Natural Resources Defense Council (NRDC), a well-respected environmental law and advocacy organization, calculates that replacing even the cleanest gasoline cars with EVs in Los Angeles would provide a reduction of hydrocarbons and carbon monoxide by 99%, nitrogen oxides by 73%, particulates by 61%, and carbon dioxide by 66%, taking out-of-state power plants into account (Natural Resources Defense Council [NRDC], 1994).

Unlike gasoline-powered cars, EVs do not produce more emissions when old or when driven erratically, nor do they have emissions control technologies that can malfunction or be disabled. Compared to gasoline-powered cars, they have fewer moving parts, require less maintenance, and produce very little noise. And, of course, EVs produce no local emissions from the vehicle itself. Although EVs may cause increased emissions at electric power plants, proponents argue that power plant emissions can be more easily controlled through advanced filter technology than the widely dispersed emissions of millions of conventional automobiles (CARB, 1994).

The Ozone Transport Commission (OTC), a policy organization representing environmental regulators from 12 northeast states and the District of Columbia, voted in February 1994 to recommend that the EPA impose the Low-Emission Vehicle regulation and accompanying ZEV mandate on the northeast region. This would require automakers to meet ZEV quotas for over one third of the U.S. motor vehicle market ("EPA Urges Compromise," 1994). The auto industry has lobbied heavily and filed several lawsuits in an effort to dissuade the EPA from approving the OTC proposal. In December 1994 the EPA approved a version of the LEV plan for the OTC region which does not include the ZEV mandate (Bureau of National Affairs [BNA], 1994).

In California, the ZEV mandate has received strong public support, but observers disagree over the extent to which this support will translate into positive consumer behavior. A survey conducted in May 1994 found 60% of Californians in support. Contrary to auto industry projections of very low consumer acceptance, 28% of respondents said they would be either "very likely" or "somewhat likely" to purchase an EV in the $20,000-$30,000 price range (Fairbanks & Associates, 1994). Given that EVs currently have a range of 50-100 miles per charge, positive assessments of EV consumer acceptance cite various studies showing that the majority of drivers travel less than 50-70 miles per day (CARB, 1994). Supporters also expect that consumer interest will rise dramatically once EVs become widely available and mass production reduces prices. These considerations indicate sufficient consumer support for implementing such ecoindustrial measures.

Criticisms of the ZEV Mandate

Criticisms of the mandate have been both technical and political, with considerable dispute concerning boundaries between the two. Technical objections to the ZEV mandate have centered on the limitations of current EV batteries. Automakers have claimed that none of the batteries currently available can provide consumers with acceptable range, speed, and rechargeability at an affordable price. Production plants, however, have to begin tooling up for the production of new vehicle models at least 3 years prior to their introduction on the market. This means that automakers will need to use the batteries and other EV technology available today, leading some to argue that the result will be angry consumers and an EV market "poisoned" for years to come (General Motors, 1994). This raises the question of whether the ZEV mandate has given automakers sufficient time to develop the technologies required. The auto industry's objections appear exaggerated on this point, especially given earlier unveilings of EV prototypes by each of the Big Three automakers. Also, various smaller companies have made huge strides in battery technology since the adoption of the mandate.

Automakers, opponents of the OTC plan, and others also argue that EVs only make sense under the specific conditions found in California. Indeed, it is quite true that the potential of EVs to reduce local and global environmental damage always depends on the method used to generate the needed electricity. Electric vehicles in California are supported by a power generation mix comprising only 16% coal. This highly polluting energy source makes up an average of over 50% of the energy-generating capacity nationwide (CARB, 1994, p. 44; Knie, 1994, p. 232). Moreover, because 80% of the Los Angeles region's electricity is generated outside of the L.A. Basin, EVs promise more benefits for that region than for the rest of California (Nadis & MacKenzie, 1993, p. 73). Although EVs will provide significant pollution reductions in California, their usefulness in other places is less clear.

Aside from their technical concerns about the viability of EVs, the major auto companies have argued that they would gladly introduce EVs, but only on their own schedule and without a state mandate (American Automobile Manufacturers Association [AAMA], 1994). The historical lack of automaker initiative in reducing motor vehicle pollution, however, speaks against the viability of such an approach. CARB originally established the ZEV mandate partly in response to the announcement by General Motors that the company would put a version of its Impact electric vehicle prototype into mass production in the mid-1990s. By December 1992, however, after ousting CEO and electric vehicle supporter Robert Stempel, General Motors announced that electric vehicle production would be delayed until the late 1990s (Sperling, 1995, p. 38). In this respect, the ZEV mandate simply holds the company to its word. A statement by Roberta Nichols, director of electric vehicle programs at Ford, supports this conclusion: "Without the environmental issues and the regulations in California, we probably wouldn't be moving the electric vehicle technology out of research" (Nadis & MacKenzie, 1993, p. 73).

Regardless of the actual pollution reduction benefits of EVs—which, at least for Los Angeles, promise to be significant—the above statement points to the importance of the ZEV mandate for both environmental and industrial development. The free

market does not usually provide sufficient incentives for industry to move forward in environmentally critical technologies. The ZEV mandate has been enormously successful in stimulating technological innovation and has started a whole new industry in Southern California.

Initial Results of the ZEV Mandate in California

According to Daniel Sperling (1995), director of the Institute of Transportation Studies at the University of California at Davis, "It was in direct response to the ZEV mandate that major investments in electric vehicle technology were finally made in the 1990s" (p. 37). CARB chairwoman Jacqueline Schafer voiced a similar view at the biennial hearings on the ZEV mandate in May 1994:

> We heard from no one who claimed the mandate had not accomplished its stated objective of stimulating technological development and innovation. While electric vehicle and battery technology may not have advanced much between the turn of the century and the 1980s, there is no doubt that tremendous advancements have occurred since we adopted the zero-emission vehicle regulation in 1990. We heard over and over again that the mandate caused or contributed to these advancements. (Sperling, 1995, p. 41)

As noted above, environmental regulations can only produce this type of technological innovation in the context of an appropriate economic and industrial infrastructure. Many factors indicate that California's current economic structure favorably corresponds to the needs of an electric vehicle industry. Although Los Angeles has never employed more than 2.8% of the country's autoworkers, 11% of total U.S. auto sales occur in California, making it the country's largest auto—and EV—market (Wolff, Rigby, Gauthier, & Cenzati, 1993, p. 74). The state has a high concentration of aerospace firms, a sector that urgently needs new contracts due to defense department budget cuts. California has lost 71,000 aerospace jobs in the last 3 years and is eager to put these people back to work (Phillips, 1994). Aerospace and defense companies in the Los Angeles Basin have the know-how to produce drivetrains, controllers, composite materials, and other components needed for electric vehicles. Innovative industrial alliances among these companies promise the development of new engine, vehicle, and transport technologies. The Lewis Center for Regional Policy Studies has identified 411 companies in the area that produce technologies relevant to electric vehicle manufacturing (Reinhold, 1992).

A 1993 survey of almost 200 auto industry experts found that 78% of the respondents thought that the prospects for a new electric vehicle industry are better today than in either the 1960s or 1970s ("Electrical vehicle deadline," 1993, p. 39). The California Electric Transportation Coalition predicts that battery manufacturing alone has the potential to generate 10,000 California jobs in the next 10 years. Finally, a California research group estimates that the ZEV mandate will lead to a national electric vehicle market of about $8 billion by the year 2003, and a worldwide market exceeding $25 billion by 2007 (CARB, 1994, p. 36).

A number of cooperative government-industry initiatives with the aim of stimulating electric vehicle technology development have been established in the United States, several in direct response to the ZEV mandate. In 1991, for example, the U.S.

Big Three auto companies brought together much of their electric vehicle development efforts under the auspices of the U.S. Advanced Battery Consortium (USABC), including participation by battery companies, a coalition of electric utilities, and the U.S. Department of Energy. In April 1993, the Big Three auto companies announced that they were considering a collaborative effort with the explicit goal of meeting California's ZEV mandate (Wald, 1993). Then in September 1993, President Clinton and the Big Three announced the formation of the Partnership for a New Generation of Vehicles (PNGV), a research consortium including the Big Three, seven Department of Energy research laboratories, and several other government agencies. Government funding was initially projected at $443 million over 10 years ("Clean-Car Project," 1994). The project's stated goal is to leapfrog current battery-run electric vehicles by focusing on the development of long-term EV technologies such as fuel cells, which convert hydrogen to electricity on board the vehicle. Some observers argue that this might in fact represent an unacknowledged attempt to undermine the ZEV mandate, which depends on the EV technologies currently available (Sperling, 1995, p. 40). Others say that the car companies have slowly backed away from their commitment to the program and the federal government has quietly turned its attention to other matters.

Far more promising have been a variety of local and regional initiatives in California. These private and public efforts all support the above predictions of the ZEV mandate's economic impact. The public-private consortium Calstart is the largest such initiative to date. Calstart was formed in 1992, funded in part by the federal Advanced Transportation Systems and Electric Vehicle Consortia Act. By 1993, the consortium had already raised $14 million in public funds and $6 million in private contributions toward its numerous projects. Its members consist of several major utilities, over 20 corporations, 4 universities and research institutions, a labor union, and an environmental organization. The consortium has three core programs: a Showcase Electric Vehicle Program, a collaboration of approximately 20 California companies working on components for electric vehicles; an Infrastructure Program, including development assistance for charging stations, service/education centers, battery recycling and disposal, public awareness campaigns, utility system impact analysis, and community integration; and an Electric Bus/Mass Transit Program seeking to develop an electric bus system in the Los Angeles area (Slifko, 1993, p. 177).

In addition to this major effort, a large number of small start-up companies and entrepreneurs—many of them located in California—have begun converting gasoline cars to electric power. About 1,000 of these had been sold to electric utilities or government agencies by 1994. The small Northern California company U.S. Electricar, for example, recently signed an agreement to install electric motors in "glider" vehicles purchased without engines or powertrains from General Motors (Sperling, 1995, p. 42). In addition to benefiting from the ZEV mandate's general stimulation of the electric vehicle market, these small companies stand to gain directly from the program's market-oriented approach. As noted above, if any of the large manufacturers fails to meet its quota for ZEVs, it will be able to buy credits from smaller companies that sell ZEVs in California.

Of course, certain electric vehicle programs were in place long before the ZEV mandate. These would include the 1976 federal Electric and Hybrid Vehicle Research, Development, and Demonstration Act that established the Electric and Hybrid Vehicle Program at the Department of Defense. The recent programs stimulated by the ZEV mandate, however, have greatly accelerated EV development. They have also put Los Angeles ahead of other regions seeking to acquire EV manufacturing investments. The commitment of many public agencies to develop an EV industry in the region has reduced the risks faced by the small entrepreneurs who are expected to provide the primary force behind the newly emerging industry. "In the specific matter of public support for the development of an electric vehicle industry, southern California is, if anything, in advance of any other region in any part of the world at the present time" (Quandt, 1993, p. 7).

The California ZEV mandate is thus serving as both an environmental regulation and a regional technoindustrial innovation policy. According to a member of Project California, a government-industry transport advisory panel, "The CARB environmentally motivated mandate . . . has taken the form of a powerful de facto socio-economic policy and, with it, California leadership [has emerged] in the eyes of the world, not only environmentally, but in ushering in this new industry" (Phillips, 1994). In the first decade of this century, electric vehicles were more popular than gasoline-powered automobiles. After an 80-year eclipse, the ZEV mandate has brought electric vehicles back into the public eye.

Conclusion

It is too soon to assess the full economic and environmental impact of the LEV/ZEV program. Almost 3 years remain until the mandate requires electric vehicles to be made available to consumers. By then the joint ventures and small start-up companies already formed in response to the mandate must secure sufficient investment and popular support to continue their activities. Otherwise, they face the fate of many similar environmental technology companies that went bankrupt during the 1980s due to a lack of interest by American investors and consumers. The environmental and economic consequences of the ZEV mandate are very promising, but as yet uncertain.

The program's gradual and predictable application has been crucial for its success thus far. It is important, in this respect, to appreciate that the ZEV mandate has not been imposed in a vacuum. It has been carefully combined with private and public efforts to secure an infrastructure for the mandated technology. Should either of these factors give way in the years to come—for example, through a weakening of CARB's resolve in the face of industry pressure to delay the mandate or through a failure to continue developing the necessary economic and technical infrastructure—the nascent electric vehicle market could quickly disappear.

Finally, it should again be noted that neither the ZEV mandate nor the electric vehicle will solve all of the social and environmental problems connected with industrial society's highly mobile way of life. In addition to the problems of electricity generation, electric vehicles, like combustion automobiles, take up street and parking space, use limited resources, and create waste products in their construction, maintenance, and disposal. As with any industrial product, these problems quickly become

apparent once the entire life cycle of an electric vehicle is taken into account (Environmental Protection Encouragement Agency [EPEA], 1992). By themselves, EVs certainly do not represent a panacea for the problems of the individual automobile. Although it does initiate a shift away from the internal combustion engine, the California program fails to challenge the dominance of the automobile in advanced industrial societies. It does not in and of itself raise the most fundamental societal question associated with the automobile and transportation more generally: Namely, how might we rethink our very understanding of mobility to conform with the sustainability demands of the next century? (Canzler & Knie, 1994).

Nevertheless, the LEV/ZEV program has demonstrated the potential advantages of a regulatory approach that combines market incentives and government mandates. It has also shown that environmental protection and technological innovation must not be treated as trade-offs. Although the applicability of California's ZEV mandate to other states and regions depends on a variety of political, economic, and administrative factors, the program's initial performance shows that there is no necessary incompatibility between reducing pollution and stimulating technological development. Given the necessary preconditions and the right approach, government can effectively direct market processes toward the provision of environmentally friendly technologies.

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Mark B. Brown is a doctoral candidate in political science at Rutgers University.

Weert Canzler is research fellow at the Wissenschaftszentrum Berlin für Sozialforschung (Social Science Research Center Berlin [WZB]).

Frank Fischer is a professor of political science at Rutgers University.

Andreas Knie is research fellow at the Wissenschaftszentrum Berlin für Sozialforschung (Social Science Research Center Berlin [WZB]).