The Effects of Vintage-Differentiated Environmental Regulation

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ABSTRACT

Vintage-differentiated regulations (VDRs) are standards that are fixed with respect to the date of entry of regulated units, with later vintages facing more stringent standards. VDRs play prominent roles under major Federal, state, and local environmental laws. This paper synthesizes what is known about the effects of environmental VDRs, and develops lessons for public policy and for research. Economic theory suggests that such age-discriminatory regulations retard turnover of the capital stock, drive up the cost of environmental protection, and can increase pollution levels. Empirical studies validate theoretical predictions that VDRs delay replacement of durable goods, and thereby increase aggregate pollution abatement costs. In some cases, empirical studies also validate the perverse consequence that environmental progress is itself retarded.

Keywords: vintage-differentiated regulation, new source review, cost-effective environmental regulation

JEL Classification: Q580, Q550, Q520, Q530, L510

THE EFFECTS OF VINTAGE-DIFFERENTIATED ENVIRONMENTAL REGULATION

Robert N. Stavins*

1. Introduction

A common feature of many environmental and other regulatory policies in the United States is vintage-differentiated regulation, under which standards for regulated units are fixed in terms of the units' respective dates of entry, with later vintages facing more stringent regulation. In the most common application, often referred to as "grandfathering," units produced prior to a specific date are exempted from a new regulation or face less stringent requirements.

This approach has long appealed to many participants in the policy community, for reasons associated with efficiency, equity, and simple politics. First, it is frequently more cost-effective — in the short-term — to introduce new pollution-abatement technologies at the time that new plants are constructed than to retrofit such abatement technologies at existing facilities. Second, it seems fair to avoid "changing the rules of the game mid-stream," and hence to apply new standards only to new plants. Third, political pressures tend to favor existing rather than potential facilities.

On the other hand, vintage-differentiated regulations can be expected — on the basis of standard investment theory — to retard turnover in the capital stock, and thereby to reduce the cost-effectiveness of regulation in the long-term, compared with equivalent undifferentiated regulations. Further, under some conditions the result can be higher levels of pollutant emissions than would occur in the absence of regulation.

In this paper, I survey and synthesize what is known regarding vintage-differentiated regulation (VDR) in the environmental realm, and develop lessons for public policy and future research. In part 2, I describe the ubiquitous nature of vintage-differentiated regulation in U.S. regulatory policy, and examine the reasons why VDRs are so common, despite the potential perverse impacts associated with these age-discriminatory policy mechanisms. In part 3, I describe a general theory of the impacts of VDRs in terms of their impacts on technology adoption, capital turnover, pollution abatement costs, and environmental performance. In part 4, I focus on the effects of VDRs in the U.S. auto industry, and in part 5, I turn to the effects of new source review. In part 6, I examine implications for policy and research.

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2. The Prevalence of Vintage-Differentiated Regulation

VDRs are found throughout U.S. regulatory policy. They are prominent features of a diverse set of Federal environmental statutes and regulations, state and local environmental laws, as well as a host of non-environmental regulations, ranging from ones that address workplace safety to ones that affect residential construction.

Within Federal environmental law, VDRs appear within the Clean Air Act in its performance standards for new versus existing stationary sources, motor vehicle and motor vehicle engine emissions standards, non-road engines and vehicles, and standards for commercial vehicles; within the Clean Water Act in a wide variety of aspects, including effluent limits for public treatment plants; as well as within the Safe Drinking Water Act, and laws affecting the generation and disposal of hazardous and solid waste (Table 1). State and local environmental laws also make frequent use of VDRs, such as for stationary and mobile source emissions limits, and energy-efficiency standards in new construction. In the non-environmental realm, VDRs are significant components of a variety of occupational health and safety laws, automotive safety regulations, consumer product safety laws, and building codes.

Why have VDRs been such a common feature of U.S. regulatory policy, despite the problems they appear to bring about? As suggested above, among the reasons frequently given by policy participants are claims that VDRs are efficient and equitable. These are not unreasonable claims. In the short-term, at least, it is frequently cheaper to control a given amount of pollution by adopting some technology at a new plant than by retrofitting that same or some other technology at an older, existing plant. Hence, VDRs appear to be somewhat cost-effective. But this is a short-term view that ignores the perverse incentive structure that such a time-differentiated standard can put in place.[1]

In terms of equity, it may indeed appear to be fair or equitable to avoid changing the rules for facilities that have already been built or products that have already been manufactured, and to focus instead only on new facilities and products. But, on the other hand, the distinct "lack of a level playing field" — an essential feature of any VDR — hardly appears equitable from the perspective of those facing the more stringent component of an age-differentiated regulation.

An additional and considerably broader explanation for the prevalence of VDRs is fundamentally political. There are very powerful incentives for VDRs to be favored by the constituencies who *demand* (in a positive political economy sense) specific types of regulatory instruments, and by the legislators who *supply* those regulations (Keohane, Revesz, and Stavins 1998).

First, on the regulatory demand side, some types of regulations can augment firms' profits through the generation of rents and erection of entry barriers. Consider a simple model of an industry made up of identical firms in long-run competitive equilibrium. If the government imposes

[1]It is by no means impossible, however, to design a VDR that accelerates investment. The nitrous oxide (NO_x) requirements under the Clean Air Act Amendments of 1990, for example, provided an inducement in the form of a less ambitious standard for early adopters.

a command-and-control standard that sets an allowable level of pollution for each firm, where firms can meet the standard only by reducing their output, the standard will lead to reduced total production and therefore an increase in price along the aggregate demand curve (Buchanan and Tullock 1975). If the environmental restriction is not exceptionally severe, the new price will be above average cost for all firms, and firms will earn rents. Firms, however, are not limited to the single response of cutting output. They can also reduce emissions by adopting a new technology or changing their input mix. In this more general and realistic scenario, command-and-control standards can still have the effect of providing rents to regulated firms, depending on the stringency of the standards and other factors (Maloney and McCormick 1982).

What is crucial for understanding the demand for VDRs from the regulated community is that the enhanced industry profitability that results from rents is sustainable over the long term *only* in the presence of entry restrictions. Thus, firms regulated by a rent-generating instrument, such as command-and-control standards, will benefit if that instrument is combined with a mechanism that imposes barriers to entry. In theory, such a mechanism might prohibit new entry outright, but a more politically feasible approach simply imposes higher costs on new entrants (Stigler 1971, Rasmusen and Zupan 1991), and that is precisely what VDR does.

This helps explain why private firms and their trade associations have strong demands for command-and-control standards, and especially for considerably more stringent command-and-control standards for new sources, which create barriers to entry. This is one important explanation for the prevalence of VDRs in U.S. environmental laws.

Another explanation arises from the existence of differential costs of environmental compliance across firms. Because of this heterogeneity, a firm may support policy instruments that impose costs on it, as long as those costs affect it less than the industry average and thus give it a competitive advantage (Leone and Jackson 1981, Oster 1982). One form of cost differential arises as a result of the erection of barriers to entry. It is important to distinguish here between the entry of new firms and the expansion of existing firms, but the entry barriers of environmental regulation generally apply to both situations. Thus, within an industry, firms with no plans to expand would derive a greater benefit from entry barriers, which could discourage further growth by their competitors.

Turning to the supply side of regulation, legislators are typically more concerned with the distribution of costs and benefits — in particular their geographic distribution — than with a comparison of total benefits and costs (Hahn and Stavins 1991). Politicians are likely to oppose instruments that may induce firms to close business and relocate elsewhere, leading to localized unemployment (Hahn and Noll 1990). Although there will be winners as well as losers from such relocation, potential losers are likely to be more certain of their status than potential gainers. This asymmetry creates a bias in favor of the status quo.

For the same reason, grandfathering is likely to be a politically expedient option for legislators, since it allows leeway in rewarding firms and distributing the costs and benefits of regulation among jurisdictions. By limiting the scope of regulation to new capital assets, the burden of regulatory compliance is concentrated on a small subset of the electorate and the cost is transferred to yet unspecified, future "new sources." In addition, the costs of such regulation are less visible when combined with major investments in new capital assets. In contrast, if regulations were to require retrofits to existing capital assets, the costs would be vastly more transparent.[2]

In summary, the prevalence of VDRs (despite their potentially perverse consequences) can be understood not only in regard to claims made about the efficiency and fairness of these approaches, but in terms of fundamental positive political economy. Demand for VDRs comes from existing firms, which seek to erect entry barriers to restrict competition and protect the rents created by command-and-control standards. In turn, environmentalists often support strict standards for new sources because they represent environmental progress, at least symbolically. On the supply side, more stringent standards for new sources allow legislators to protect existing constituents and interests by placing the bulk of the pollution control burden on unbuilt factories.

3. An Initial Theory of the Impacts of Vintage-Differentiated Regulation

The basic theory of the impacts of vintage-differentiated regulation draws upon the general theory of the determinants of the age of existing capital.[3] Consider a simple model in which the production decision can be characterized by the choice of two variables: the number of pieces of homogeneous durable equipment (of some specific type) to be operated, and the lives of each of these devices. Inevitably, the pieces of durable equipment — "machines" — degrade over time, that is, they wear out. This can be characterized by maintenance costs that rise as the machines age. If perfectly competitive firms seek to maximize their profits, then new machines will be placed in service if:

$$\int_0^T [NR - C(t)]e^{-rt}dt \;\geq\; M \tag{1}$$

were NR is net revenue per machine, $C(t)$ is maintenance cost as a function of time, r is the interest rate, M is the initial cost of the machine, and T is the machine's useful life. The present value of the profit stream associated with a series of such machines over an infinite time horizon is then:

$$\Pi = \frac{\int_0^T [NR - C(t)]e^{-rt}dt - M}{1 - e^{-rT}} \tag{2}$$

Differentiating equation (2) with respect to T yields the following first-order (necessary) condition for profit maximization:

$$NR - C(T) = r\Pi \tag{3}$$

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[2]In the context of automobile emissions regulation, Crandall *et al.* (1986) noted that "owners of existing equipment can organize to fight regulation that adversely affects their interests. For instance, California automobile owners successfully fought retrofit requirements in the 1960s. In contrast, future purchasers of new equipment do not constitute as cohesive an interest group; therefore regulation tends to be focused upon new vehicles" (p. 89).

[3]See Gruenspecht (1981) for a detailed theoretical model of differentiated regulation. The simpler model employed here follows Maloney and Brady (1988).

The firm should continue to add machines until the marginal profit of the last machine is zero. Since for any given machine, Π equals zero under perfect competition, the intuitive profit-maximizing rule in equation (3) indicates that machines should be run until (increasing) maintenance costs equal net revenues.

Vintage-differentiated environmental regulation fits into this simple model of capital replacement, because VDR endows old machines with a value that cannot be transferred, since new machines are rendered systematically more costly. The effective price of new capital is increased. In order for equation (1) to be satisfied as an equality, *NR* must increase, and so — by equation (3) — *T* increases. Old capital is retired at a later date. Hence, the average age of capital increases and the rate of investment decreases.[4]

A more specialized model, with explicit representations of product and pollutant output (Gruenspecht 1981) reinforces the finding that VDR (in which there is a systematic bias against new sources) has the effect of retarding the rate of turnover of the capital stock, thereby driving up abatement costs, compared with what they would be with an otherwise equivalent undifferentiated regulation. Strikingly, the relationship between aggregate pollutant emissions and regulatory stringency can be perverse, with more stringent regulation leading to increased aggregate emissions. This can occur when VDR is applied in the context of technologies for which newer vintages have lower pollutant emissions (even in the absence of the vintage differentiated regulation).[5] Such conditions are typical, not atypical, in the environmental and some other regulatory spheres. Thus, increasing the stringency of a VDR can drive up costs *and* simultaneously drive down benefits (increase emissions). This perverse outcome is due to the simple reality that decisions regarding investment in new facilities and decisions regarding retirement of old facilities both depend upon the cost of meeting regulatory standards for the new facilities.

Thus, the general theory of the impacts of vintage-differentiated regulation flows directly from neoclassical capital theory, indicating that a regulatory bias against new sources will reduce investment in new facilities and lengthen the economic life of existing facilities. Most remarkable, more stringent VDRs can actually be counter-productive, increasing the aggregate emissions level, rather than reducing it (Gruenspecht 1982). Although a more stringent VDR ultimately would lead — in theory — to lower aggregate emissions, the perverse impacts on investment can lead to short-term emissions increases.

This trade-off between short-term and long-term impacts becomes most problematic when the sources subject to regulation have especially low rates of deterioration and technical obsolescence, conditions which are met by power plants (emissions standards) and buildings (zoning and building codes). In these cases, the "short term" is very long, and vintage-differentiated

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[4]A more complex model would also allow for endogenous maintenance. As is discussed in sections 4 and 5, below, VDRs create incentives to extend the useful lives of equipment in two ways: keeping it longer (as in the model above); and investing more in maintenance throughout the life of the equipment than would otherwise be the case. This reinforces the capital investment effect examined above. For a general discussion of endogenous maintenance, see: Keohane, Roy, and Zeckhauser (2000).

[5]These effects are heightened, of course, if the older technology in question exhibits increasing emissions (degraded abatement) as it ages.

regulations are likely to be particularly problematic. Whether the extreme, counter-productive outcome actually occurs, however, is ultimately an empirical question.

4. Vintage-Differentiated Regulation in the U.S. Auto Industry

Vintage differentiation has been a prominent feature of U.S. motor vehicle regulation, including automobile emissions standards under the Clean Air Act, automotive safety standards under the National Traffic and Motor Vehicle Safety Act (1966), and the Corporate Average Fuel Economy (CAFE) standards under the Energy Policy and Conservation Act amendments (1975). In all three cases, more stringent standards apply to vehicles of later vintages.

4.1 Theoretical Analysis of the Effects of Automobile VDR

A theoretical model of the effects of automobile VDR is essentially a model of the scrappage decision regarding a durable good. It is intuitive that a necessary condition for optimal behavior where markets for both new and used cars exist is that cars are retired (scrapped) if and only if:

$$(P - SV) < P_R \cdot R \tag{4}$$

where P is market value for a car in operable condition, SV is the car's scrap value, P_R is the repair price, and R is the repair quantity or degree (Gruenspecht 1982).

Since new and used cars are substitutes, any increase in the price or operating costs of new cars — such as that due to vintage-differentiated regulation — causes substitution to used cars, increasing demand in that relatively inelastic market (thereby driving up the price of used cars). The result is that the economic lives of used cars are extended; that is, scrapping rates fall, and there are more cars of the older vintage on the road. Since the emissions of older vintages of cars are greater than newer vintages, the delay in retiring vehicles can result in counter-productive increases in aggregate emissions. Whether or not such emission increases occur is an empirical question, and two of the key variables are the price elasticity of scrappage and of new vehicle sales.[6]

In a comprehensive assessment of automotive regulation, Crandall, Gruenspecht, Keeler, and Lave (1986) raised three primary concerns.[7] First, because VDR increases the price of new cars it affects the used car market (as outlined above), and so provides incentives for extension of the useful lives of automobiles, which can "partially or fully offset the direct emissions reducing impact of tighter standards for a considerable period" (p. 89). Second, since VDR establishes a direct linkage between the rate of fleet turnover and environmental performance, when new car sales fall below expectations (for any reason), environmental progress can be compromised. Third, VDRs for

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[6]The possibility of developing public policies aimed at increasing the rate of turnover of the automobile fleet as a means of reducing aggregate pollutant emissions has led to a parallel set of investigations — both theoretical and empirical — of "accelerated vehicle retirement programs." See, for example: Hahn (1995); and Alberini, Harrington, and McConnell (1995).

[7]In an earlier theoretical study, Kwoka (1983) demonstrated that CAFE alters the mix and total number of vehicles in the fleet in ways that could "partially or even fully offset the fuel savings envisioned by a rising CAFE" (p. 696).

automobiles provide no incentives for individual car owners to maintain their emissions control systems (in the absence of inspection programs).

4.2 Empirical Analysis of the Effects of Automobile VDR

A central question for empirical analysis is whether with a durable good with a relatively rapid rate of capital turnover, such as with motor vehicles, VDRs could nevertheless result in counter-productive impacts on aggregate emissions. To investigate this, Gruenspecht (1982) econometrically estimated the key elasticities from empirical data, and combined these with an independent estimate of the cost penalty associated with the 1981 new car emissions standards for carbon monoxide (CO) and nitrogen oxides (NO_x), and thereby was able to calculate the effect of the adoption of the more stringent new car standards on auto scrappage rates. From this, he could estimate the net impacts of the VDR on aggregate emissions.

He found that the VDR had depressed new car sales by between 2% and 5% over the first five years after the regulation came into force, and as a result CO emissions were actually increased by the regulation by about 1% over the first four years, hydrocarbon (HC) emissions by up to 2%, while NO_x emissions were uniformly decreased by regulation. Of course, even the CO and HC effects were "short term." Six years after the regulation had come into effect, emissions of all three pollutants had declined — 4.5% below baseline for CO by 1990, and 15% below baseline for HCs by that year. Thus, counter-productive environmental performance was a temporary phenomenon in this case.[8] But the impacts of the VDR on delaying turnover in the vehicle fleet meant that emissions were not reduced as much as the legislative standards would suggest (Crandall, Gruenspecht, Keeler, and Lave 1985) and the cost-effectiveness of the policy was reduced.

The vintage-differentiated regulations explicit in motor vehicle emissions laws and CAFE standards have been contrasted with alternative approaches. For example, Gruenspecht (1982) considered a $250 "bounty" for scrapping of 15-year old cars. The result, not surprisingly, is environmental performance that is better than either the actual VDR or the absence of it. In a similar vein, a 1991 study by DRI/McGraw-Hill contrasted the CAFE program with accelerated vehicle retirement programs, and found that the latter would be more effective at reducing fuel consumption and emissions, provide greater benefits to the economy, and be more cost-effective, but that the difference between the two approaches would decrease over time.[9]

The CAFE program has also been contrasted with commensurate gasoline taxes, and found to be a more costly regulatory option for improving fuel economy (Crandall 1992). This comparison goes well beyond VDR, of course, because there are other reasons why CAFE standards are a relatively costly means of achieving fuel conservation, in addition to the component of CAFE that features vintage differentiation.[10] Nevertheless it should be noted that CAFE adds to the cost of new

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[8]The long-term favorable effects on emissions of the retirement of older vehicles is documented by Kahn (1996).

[9]See also: Harrington, Alberini, and McConnell (1996).

[10]For assessments of the CAFE program's costs relative to equivalent gasoline taxes, see: Crandall et al. (1986); Goldberg (1997); National Research Council (2002); and Parry, Fischer, and Harrington (2004).

vehicles, and so reduces new car sales, and extends the life of old vehicles (and has no fuel-use reducing effects on old vehicles). This contrasts with a gasoline tax, which increases the marginal cost of driving for all vehicles, but induces the trading in of old fuel inefficient cars for newer, more fuel efficient ones by increasing the cost of operation of older cars. How serious have these effects been? Estimates of the welfare costs of CAFE range from $0.41 to $0.63 per gallon of gasoline conserved, compared with welfare costs of $0.08 per gallon conserved for a 2.4 cents per gallon tax, indicating a five to eight-fold cost differential (Crandall and Graham 1989; Greene 1990; Kleit 1990; Leone and Parkinson 1990). Not too much should be made of this comparison, however, since the CAFE program is, in essence, much more stringent than a 2.4 cents per gallon gasoline tax. If the marginal costs of fuel efficiency increase over the relevant domain, which is the case, then on this basis alone, one would anticipate some cost differential.

It is worth noting that the same behavior on the part of vehicle owners that stems from the perverse incentives of VDRs was also demonstrated to arise in the context of the California Air Resources Board's former 1990 requirement that automobile manufacturers include zero-emissions vehicles (ZEVs) in their 1998 California sales mix. Although the requirement would have reduced slightly emissions from the average new car sold in the state, the program would also have had the effect of increasing prices of both electric (ZEV) and non-electric vehicles, as manufacturers spread the costs of developing the ZEVs and the subsidies needed to induce consumers to buy them. Gruenspecht (2001) found that new car purchases would consequently fall by between 2% and 3%, with a commensurate increase in the retention of older cars in the fleet. The analysis indicates that the extra emissions thereby generated would more than offset the emissions reductions from the ZEVs.

5. New Source Review

The Clean Air Act's New Source Review (NSR) program is a widely studied example of vintage-differentiated regulation, particularly as it relates to the coal-fired electricity generation sector.[11] NSR sets emissions control requirements for new sources and for sources that are being expanded or modified significantly. The regulations thereby exclude existing facilities from emissions control requirements (U.S. Environmental Protection Agency 2001), essentially requiring new or upgraded power plants and some other types of facilities to be cleaner than old ones.[12] Not surprisingly, concern has been raised that NSR thereby wastes resources and can retard environmental progress.[13]

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[11]In 2003, the Bush administration initiated changes in the New Source Review program. All of the research considered in this paper, however, deals with the program prior to those changes.

[12]See: Clean Air Act, Air Pollution Prevention Control, U.S. Code Title 42, Chapter 85, Subchapter 1, Part A, Section 7411 (B)(1)(b).

[13]See, for example: Gruenspecht and Stavins (2002a, 2002b).

The NSR program applies to any new source whose potential emissions at full utilization are high enough to qualify it as a major source.[14] The program also applies to any modification at an existing major source that results in an emissions increase. In addition to securing a permit prior to commencing construction or modification, sources subject to NSR must achieve emissions rates that reflect the performance of the best-available emissions control technology. NSR sources located in areas that do not meet national ambient air quality standards are also required to secure offsets for their emissions.

The NSR requirements under the Clean Air Act date back to the 1970s. Those who wrote the Act presumably thought they could secure greater environmental progress by imposing tougher emissions standards on new power plants (and certain other emission sources) than on old ones. The frequently-voiced theory was that emissions would fall as old plants were retired and replaced by new, cleaner plants.[15] Critics claim that experience over the past 25 years has shown this approach to be both excessively costly and environmentally counterproductive, because firms have been motivated to keep old (and dirty) plants operating and to hold back on investments in new (and cleaner) power generation technologies.

5.1 NSR and New Power Plants

NSR can create perverse environmental incentives, especially when major technology advances make new plants much cleaner than old ones. Several studies have empirically examined the hypothesis that NSR in the electricity generation sector has extended the useful lives of plants and delayed the construction of replacement capacity, thereby having a perverse effect on emissions abatement.

One study examined the relationships between regulation and capital turnover, and capital age and emissions (Maloney and Brady 1988). In both time-series and cross-sectional econometric analyses, the researchers found a statistically significant inverse relationship between the rate of new plant investment and air quality regulation, controlling for other relevant variables. In a second stage, the relationship between air quality regulation and SO_2 emissions was examined. The authors conclude that "these results convince us that regulation has induced delay in the retirement of capital and that this delay has been detrimental to the improvement of the environment" (Maloney and Brady 1988, p. 222).[16]

A second study, working with different data, provided partial support, finding that "increases in regulatory intensity lead firms to delay the construction of new steam-generating plants" (Nelson, Tietenberg, and Donihue 1993, p. 371). In this case, the researchers found that over the period, 1969-1983, environmental regulations increased plant age by more than 22 percent. But, for the

[14]The cut-off value used to determine whether a source is major generally varies between 10 and 100 tons of emissions per year, depending on the source category and the severity of any air quality problem where the source is located.

[15]For a historical perspective on the development of the 1978 new source standards, see Ackerman and Hasler (1981). An early assessment of the effects of the regulations was provided by Gollop and Roberts (1983).

[16]Also see: Nelson (1984).

most part, the study did not find a significant effect of plant age on emissions. The reason for this may be in an earlier study by Joskow and Schmalensee (1987), which found that fuel efficiency in coal-fired plants improved throughout the 1960s, but stabilized in the 1970s (and may even have declined for some new units). If fuel efficiency was related to emissions, then older plants may not have been more polluting than newer ones during that period.

An analysis by Swift (2000) illustrates how NSR requirements can impede the adoption of cleaner and more efficient energy technologies, such as combined heat and power (CHP) systems.[17] Swift found that NSR rules pose a deterrent to the spread of CHP technology, although it is difficult to disentangle the effects of the regulation's technology-standard approach from the effects of the regulation's NSR component *per se*. In any event, the rules require the application of end-of-pipe control technology to an already clean turbine with very low emissions. This requirement can significantly increase the cost of a CHP project and removes only a small amount of pollution, resulting in a very high cost-per-ton of removal, more than $25,000 by Swift's estimate, or 25 to 75 times the cost of emissions reductions available from existing sources.

In addition to delaying capital stock turnover, NSR can promote environmentally perverse decisions regarding the use (dispatch) of new capacity. In this case, the hypothesis is that NSR changes the operating costs of plants of various vintages in ways that provide incentives for companies to favor the utilization of older plants over newer ones (with more stringent emissions control technologies). For example, new coal-fired power plants built following passage of the 1977 Clean Air Act Amendments were required to build and operate scrubbers to remove sulfur dioxide (SO_2) emissions. But the costs of running scrubbers were high enough that new coal-fired plants were more expensive to operate than many older ones, which were not regulated under a new source standard. Under these conditions, utilities might be expected to reduce output from their new, scrubbed units while operating older plants at full capacity during off-peak seasons and time periods. These effects were validated empirically in an econometric analysis by Stanton (1993). Thus, by reversing the usual preference for maximizing use of the most modern capacity, vintage-differentiated regulation reduced the environmental benefits resulting from the mandated investment in expensive scrubbing equipment.[18]

5.2 NSR and Existing Power Plants

NSR applies to existing plants only if they carry out a major modification that results in a net increase in emissions. This approach — which at first may sound perfectly reasonable — brings

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[17]In a modern CHP system, fuel is burned in a turbine to generate electricity, and the waste heat from combustion, which in conventional stand-alone generation systems is vented to the atmosphere, is used in commercial or industrial processes at the site. A new CHP installation using a gas-fired turbine with low-nitrogen oxide burners and no end–of–pipe emissions controls substantially reduces nitrogen oxide emissions from levels that would result from the continued operation of an existing onsite boiler to provide process heat and an offsite power plant to provide power. CHP also allows for a substantial reduction in the total primary energy input required to meet heat and power needs, yielding economic benefits and lower carbon dioxide emissions.

[18]The SO_2 allowance trading program, implemented under the Clean Air Act Amendments of 1990, overcame the inefficiencies in SO_2 regulation associated with NSR-type programs. For a review of the effects of NSR under the Clean Air Act, see: Swift (2001).

with it several problems (Gruenspecht and Stavins 2002b). First, old plants typically emit the vast majority of total pollution in any sector, but NSR does not provide a continuous and effective incentive for emissions reductions at these plants. As a result, many of the most cost-effective emissions reduction opportunities are simply left untouched. Second, because the lengthy and costly NSR process is triggered by "modifications," the NSR program provides a powerful disincentive for improvements and efficiency upgrades at old plants.[19] Since adjusting existing equipment to perform better can be a source of pollution reductions as well as cost savings, the effect of NSR can be both economically and environmentally harmful. Third, NSR creates a highly uncertain environment with potentially high transaction costs.[20]

Current interpretations and implementation of NSR may discourage companies from maintaining their existing facilities. Plant owners contemplating maintenance activities must weigh the possible loss of considerable regulatory advantage if the work crosses the murky line between upkeep and improvement. Protracted, costly, and time-consuming legal wrangling is inevitable over whether maintenance activities have crossed a threshold sufficient to justify forcing an old plant to meet new plant standards. In the electricity sector, the deferral of maintenance compromises generation plant reliability, and thereby increases the risk of outages.[21]

5.3 NSR in Other Sectors

Although most empirical analysis regarding New Source Review has focused on the electricity generation sector, a number of studies have been carried out in other areas as well. As early as 1979, Hartman, Bozdogan, and Nadkarni analyzed the economic impacts of the Clean Air Act, including NSR, and detected what may be the first evidence of negative effects on capacity growth. And in the early 1980s, in an analysis by Crandall (1983) of eight industrial sectors, quantitative estimates were offered of what was then characterized as "new source bias."

Much closer to the point is a more recent study examining whether the timing of plant investments was affected by the nature of regulation (Becker and Henderson 2000). In a study of

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[19]The finding of a major modification inevitably raises tricky issues in situations where changes are made to an existing plant. The combination of delay cost, control technology costs, and the cost of emissions offsets create a powerful incentive for existing sources to avoid triggering NSR. Existing plants can avoid triggering NSR requirements by demonstrating that a modification, even if major, does not increase emissions. For steam-electric generating units, actual emissions before the change are compared with projected emissions after the change to determine whether a modification increases emissions. Modifications that allow a plant to produce more electricity per unit of fuel burned can lead to an increase in its projected future emissions, since better efficiency will often result in higher projected utilization. Such projects can trigger NSR, even if they reduce emissions in the region, considering induced changes in the utilization of other facilities.

[20]Routine maintenance, repair, and replacement activities are recognized as falling outside the scope of the NSR program, but the line separating these activities from a change that would be covered by the NSR process is subject to uncertain and changing interpretation. Several enforcement actions against electric generators were initiated in 1999, alleging that the utilities had evaded NSR requirements by improperly classifying major upgrade and life-extension projects as activities that do not count as major modifications under EPA's regulations.

[21]For further discussion of the ways in which NSR may impede reinvestment in existing capital stock due to the uncertainty implicit in the NSR process, see: U.S. Environmental Protection Agency 2002.

several industries over the period, 1963-1992, the researchers found that NSR significantly depressed the "birth" of new plants, keeping old plants on line. In an empirical analysis of the organic industrial chemicals industry, Becker and Henderson found that grandfathering of plants contributed to environmental degradation by raising survival rates, reducing plant turnover rates, and keeping otherwise unprofitable operations in business. This also had the effect, the authors pointed out, of slowing improvements in air quality, because the lives of older, dirtier plants were prolonged. They concluded that, "a more uniform policy with respect to age would have encouraged retrofitting and other antipollution activities of existing VOC and NO_x emitters much earlier in the regulatory process" (p. 415).[22]

6. Implications for Policy and Research

The theoretical and empirical findings regarding VDRs, reported above, have implications for public policy in the environmental realm. Likewise, the results from previous studies point the way to promising areas for future research.

Previous research has shown that VDRs drive up costs and can result in worse environmental quality than would have occurred if firms faced cost-effective regulation rather than the disincentive to invest in new, cleaner technologies. And in some limited cases, VDRs may actually lead to worse environmental quality than would result from an absence of regulation. But environmental regulation is often necessary to achieve emissions reductions. If — in some cases — it would make sense to abandon vintage-differentiated regulations, what should be put in their place?

In the context of point sources, such as in the electricity generation sector, one approach would be to move toward a level playing field, that is, even-handed regulation that motivates both old and new plants to cut emissions in order to achieve environmental objectives. This might be accomplished through a cap on total pollutant emissions together with the use of an allowance trading system to assure that any emissions increases at one plant are balanced by offsetting reductions at another. The SO_2 allowance trading program in the 1990 Clean Air Act is one among many possible models (Stavins 1998). No matter how emissions are initially allocated across plants, the owners of existing facilities and those who wish to build new ones would face appropriate incentives with respect to retirement decisions, investment decisions, and decisions regarding the use of alternative fuels and technologies to reduce pollution.[23]

Thus, in principle, it should be possible to strengthen environmental laws by selectively and gradually phasing out reliance on vintage-differentiated regulations and replacing these age-discriminatory mechanisms with binding environmental constraints, sometimes implemented through cost-effective, market-based policy instruments.

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[22]"VOC" refers to volatile organic compound.

[23]Presumably requirements for localities to meet ambient air quality standards would remain in effect, preventing a concentration of emissions allowed under the cap in any geographic region that would conflict with needs "to protect public health with an adequate margin of safety."

How might such selective and gradual phasing out proceed? Research has identified important trade-offs regarding the use of VDRs, including: short-term emissions increases verus long-term emissions reductions; and increases in unit abatement costs versus reductions in pollution levels. Hence, it is necessary to ask *which* VDRs should actually be targeted for phase out? Much remains to be learned if such priorities are to be established. A key question to address is what are the circumstances under which VDRs are most likely to be welfare-reducing compared with viable alternatives?

Some of the relevant factors determining the conditions under which VDRs are particularly troublesome can be identified, but more research will be needed to establish the relationships with rigor and to quantify the magnitude of the respective effects. The list of candidates for further analysis includes the following.

First, the longer is the "natural economic life" of the relevant durable good, the greater is the scope for VDRs to reduce the rate of turnover of the capital stock. This is one of the reasons why the investment-retarding impacts of the New Source Review program have been so pronounced in the electricity generation sector, particularly for large-scale, coal-fired plants. It is also the reason why the impacts of VDRs in the automotive sector may be becoming more severe over time. As the quality of motor vehicles has greatly improved, the average life of vehicles on the road has nearly doubled over the past twenty-five years.

Second, if the rate of relevant technological change is great, that is, if newer vintages of given machines are also much cleaner, then VDRs can lead to an unintended inverse relationship between the stringency of regulation and aggregate emissions. Third, the negative impacts of VDRs on pollution levels are heightened if the older technology in question exhibits increasing emissions (degraded abatement) as it ages.

Fourth, market structure matters. For example, selective deregulation of electricity markets has presumably rendered affected generators more sensitive to environmental compliance costs than they were in a world of rate-of-return regulation where regulatory commissions would typically permit such compliance costs to be passed on to rate payers. This suggests that the negative consequences of VDRs have been increasing, *ceteris paribus*, in this sector during the period of deregulation. Questions remain not only regarding this linkage, but also regarding a variety of other ways in which market structure might affect the performance of VDRs.

Fifth and finally, the underlying regulatory structure itself is of significance. In theory, VDRs can be employed within the context of command-and-control instruments, such as technology-based standards, or within market-based systems, such as tradeable permits.

Thus, while theoretical arguments against the use of VDRs are quite compelling, there is considerable need for more empirical analysis examining the actual effects of these age-discriminatory mechanisms in practice. Three areas of potentially productive research stand out: the role of market structure in determining the effects of VDRs; the impact of VDRs on motor vehicle turnover rates; and the performance of VDRs combined with alternative policy instruments.

6.1 The Role of Market Structure

One area of research that has not been explored despite strong theoretical evidence to suggest its relevance is the role of market structure in determining the effects of VDRs. Theoretically, more competitive markets should exhibit more severe consequences from VDRs, since the competitive nature of these industries forces firms to seek cost savings wherever possible, including through prolonging the life of capital equipment in order to avoid incurring higher pollution abatement costs. Less competitive industries should be less vulnerable to such cost-saving pressures. A natural experiment of the effects of market structure on the effect of VDRs occurred in the United States when several regions deregulated electricity markets while remaining regions maintained rate-of-return regulations. It would be illuminating to compare the rates of capital turnover in states with deregulated systems with states with regulated systems.

A variety of challenging methodological issues will need to be addressed in such research. First, there is the possibility that the policy variable — deregulation — is itself endogenous. The concern would be that unobservable factors that affect whether or not a plant is subject to deregulation also affect the frequency of pollution control equipment installation. If relevant deregulation decisions were largely political, then they were exogenous to the rate of capital turnover. On the other hand, states that had the greatest costs from rate-of-return regulation may have been those that opted to deregulate. If the latter were true, it would be essential to test whether the degree of inefficiency in the regulated system is correlated with the rate of turnover. In either case, a careful consideration of the endogeneity issue is required.[24] The gradual and partial deregulation of the electricity generation industry is a promising natural experiment for analyzing the effect of market structure on capital turnover rates.

6.2 Impacts on Turnover of Mobile Capital

More research is also needed on the rate of turnover of mobile capital, in particular automobiles. It is commonly accepted that the current generation of cars is more durable than the cohort built a decade ago, but new car sales are also on the rise. One can define the gross turnover rate to be car retirements less new car sales, and the net turnover rate to be the gross turnover rate plus transfers out of the policy jurisdiction. Then, the increased longevity of automobiles combined with an increased sales rate implies that the gross turnover rate has been declining. But it is possible that the *net* turnover rate of automobiles has actually increased over the last decade. This would be the case if more people are buying newer cars, *and* if the older cars, which have a longer life, are leaving the country (or state, in the case of California regulations).[25]

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[24]In addition, there might be a concern about the validity of the natural experiment if states that were not deregulated anticipated being deregulated in the near future. If there is uncertainty over future deregulation, then regulated states might not be a good control for what would have happened to the rate of capital turnover in the absence of deregulation.

[25]In some policy situations, the relevant turnover rate would be the net rate. Older cars leaving the state or being sold in Mexico would not affect the ultimate policy outcome. This would be the case for local air pollution in Los Angeles, for example. But if California is employing CO_2 standards for climate change policy, then old cars going to Mexico constitute a problem. In this case, the relevant turnover rate would be the gross rate.

A second natural experiment that might illuminate the effect of VDRs on the rate of turnover of automobiles comes from selective state implementation of vintage-differentiated safety and emissions tests. In the northeastern states, for example, emissions test requirements are less stringent for older automobiles. Other states do not have emissions tests at all. This variation across states provides for the possibility of examining the effects of VDRs on automobile turnover rates. As with the possible study of the effect of deregulation on capital turnover in the electricity sector, this study would have to address the potential endogeneity of the policy variable. In particular, the density of urban areas in the northeast and the existence of reliable public transportation services may lead to lower turnover rates for automobiles in these states, even in the absence of VDRs.

6.3 Performance of VDRs Combined with Alternative Policy Instruments

A third area of promising research concerns the interaction of VDRs with alternative policy instruments. As indicated above, Swift (2000) demonstrated that NSR requirements slowed the adoption of combined heat and power (CHP) systems. In that case, combining vintage-differentiation with a technology standard worsened the effects of NSR. Despite the fact that CHP systems were already highly efficient with low emissions, the technology standard required the addition of costly abatement equipment. Hence, plants reasonably decided to forgo adopting CHP systems altogether. The effect of vintage-differentiation might have been substantially less if the underlying regulation were performance-based rather than technology-based.

One can imagine VDRs combined with alternative policy instruments in which the negative effects of VDRs are reduced, if not eliminated. The use of the SO_2 allowance trading system in conjunction with NSR under the Clean Air Act Amendments of 1990 may provide the basis for empirical analysis of the effects of VDRs under alternative policy regimes. Prior to the Clean Air Act Amendments of 1990, affected facilities were regulated under a command-and-control system combined with VDR, but after the 1990 Amendments came into force, some plants were regulated under the allowance trading (cap and trade) system. This combination of temporal and spatial variation may provide data for empirical research.

6.4 Conclusion

In this paper, I have assessed what is known about the effects of vintage-differentiated environmental regulations, which are fixed with respect to the date of entry of regulated units, with later vintages facing more stringent standards. VDRs play prominent roles under major Federal environmental statutes, state and local environmental laws, and a variety of non-environmental regulations. This is despite the fact that economists and others have long argued that such age-discriminatory regulations retard turnover of the capital stock, drive up the cost of environmental protection, and may retard pollution abatement. The major explanations for the frequent reliance on VDRs in U.S. policy are found in the powerful political incentives that exist for these approaches to be favored by key constituencies who demand specific types of regulatory instruments and by legislators who supply regulations.

With roots going back to standard investment theory, models of the impacts of vintage-differentiated regulation have been developed over the past twenty-five years, with empirical analysis in the environmental realm having accelerated over the past twenty years. Much of the focus of that empirical analysis has been on VDRs in the automotive sector and on New Source Review in the electric power generation sector. Overall, the rather sparse empirical studies have validated theoretical findings that, *ceteris paribus*, vintage-differentiated regulations have had the effect of retarding the turnover of durable goods, and have thereby driven up aggregate pollution abatement costs. In some cases, empirical studies have also validated the particularly perverse potential consequence of this approach to environmental regulation — environmental progress has itself been slowed.

These theoretical and empirical findings point the way to what could be significant improvements in public policy in the environmental realm. At the same time, more remains to be learned, and additional research efforts in this area are likely to produce unusually large dividends.

TABLE 1: Examples of Vintage Differentiated Regulations in U.S. Environmental Law

Regulatory Area	Application	Statute
Air Quality	Performance Standards for New and Existing Stationary Sources	Clean Air Act, Air Pollution Prevention Control, U.S. Code Title 42, Chapter 85, Subchapter 1, Part A, Section 7411, versus Subchapter II, Part A.
	Motor Vehicle and Motor Vehicle Engine Emissions Standards	Clean Air Act, Air Pollution Prevention Control, U.S. Code Title 42, Chapter 85, Section 7521.
	Non-Road Engines and Vehicles	Clean Air Act, Air Pollution Prevention Control, U.S. Code Title 42, Chapter 85, Section 7547.
	Commercial Vehicle Standards	Clean Air Act, Air Pollution Prevention Control, U.S. Code Title 42, Chapter 85, Section 7554 sets standards that apply only to buses manufactured subsequent to the 1993 model year.
Water Quality	Effluent Limits for Public Treatment Plants	Clean Water Act, U.S. Code Title 33, Chapter 26, Subchapter III, Section 1311 (a)(1)(B) and (C) sets differential standards for plants in operation prior to July 1, 1977.
	Drinking Water Treatment	Safe Drinking Water Act, U.S. Code, Title 42, Chapter 6A, Subchapter XII, Part B, Section 300g-9 (d)(4) requires EPA to set standards for new plants.
Waste Management	Generation and Disposal of Hazardous and Solid Waste	Hazardous Waste Management Sections: U.S. Code Title 42, Chapter 82, Subchapter III, Section 6925.
State & Local Environmental Laws	Stationary and Mobile Source Emission Limits; Energy-Efficiency Standards for New Construction; etc.	For example, California Air Resources Board regulations, Health and Safety Code Division 26, Part 2, Chapter 3.5, Article 4 sets differentiated emissions standards for new vehicles.

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