MOVING TO MARKETS IN ENVIRONMENTAL REGULATION

Lessons from Twenty Years of Experience

Edited by
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The Market-Based Lead Phasedown

Richard G. Newell & Kristian Rogers

INTRODUCTION

One of the great successes during the modern era of environmental policy was the phasedown of lead in gasoline, which took place in the United States principally during the decade of the 1980s. The phasedown was accomplished in part through a tradable permit system among refineries, whereby lead credits could be exchanged or banked for later use. The lead trading program represents the first large-scale implementation of a tradable permit program for the environment, predating the well-known sulfur dioxide trading program by more than a decade.

Unlike sulfur in coal, however, lead does not occur naturally in petroleum. Refiners in the United States started adding lead compounds to gasoline in the 1920s to boost octane levels and improve engine performance by reducing engine knock and allowing higher engine compression.[1] Lead was used because it was inexpensive for boosting octane relative to other fuel additives (i.e., ethanol and other alcohol-based additives) and because people were ignorant of the dangers of lead emissions, including mental retardation and hypertension. In the early 1970s, before legal requirements for reducing lead came into force, lead levels in gasoline were a little over 2 grams of lead per gallon of gasoline, amounting to about 200,000 metric tons of lead in total. The reduction in lead in gasoline in the United States came in response to two main factors: (1) the mandatory use of unleaded gasoline to protect catalytic converters in all cars starting with the 1975 model year, and (2) increased awareness of the negative human health effects of lead.

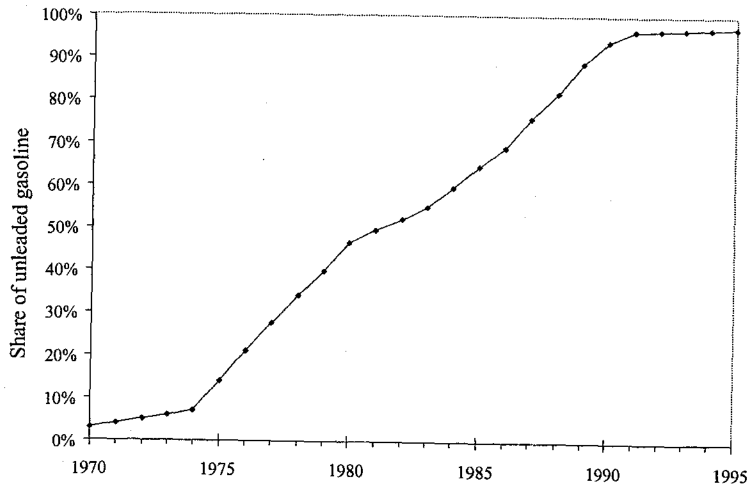

Figure 7.1. Share of Unleaded Gasoline in Total U.S. Production
Source: Petroleum Marketing Monthly, Statistical Abstracts, and other sources. See Kerr and Newell (2003).

averaging method deliberately provided refiners with the incentive to increase unleaded production while not necessarily removing lead from their leaded gasoline—in fact, the regulation actually allowed refiners to increase lead concentration levels, provided they sufficiently raised unleaded gasoline output. Nonetheless, these regulations still prompted a decrease in total lead usage because car owners were retiring their precatalyst automobiles and replacing them with new cars that required unleaded fuel.

As illustrated in figure 7.2, by the early 1980s gasoline lead levels had declined about 80 percent as a result of both the regulations and the fleet turnover. As part of President Reagan's Task Force on Regulatory Relief, the EPA considered deferring the deadlines and relaxing the standards in response to growing complaints from lead additive manufacturers (who contended that the lead regulations were unnecessary because lead was on its way out anyway) and small refiners who were having difficulty complying on time. Due to mounting evidence on the negative health effects of lead, however, this consideration met very strong opposition, both from within the agency and from environmental groups and public health officials. The agency subsequently withdrew its consideration and instead decided to tighten the standards. The 1982 regulations narrowed the definition of a small refinery, phased out special provisions for such refineries by mid-1983, and recalculated lead limits as an average of lead in leaded gas only (because unleaded fuel was by then a well-established product). Small refineries challenged the new regulations but gained only a slight extension in some of their compliance deadlines.[3] The new rules

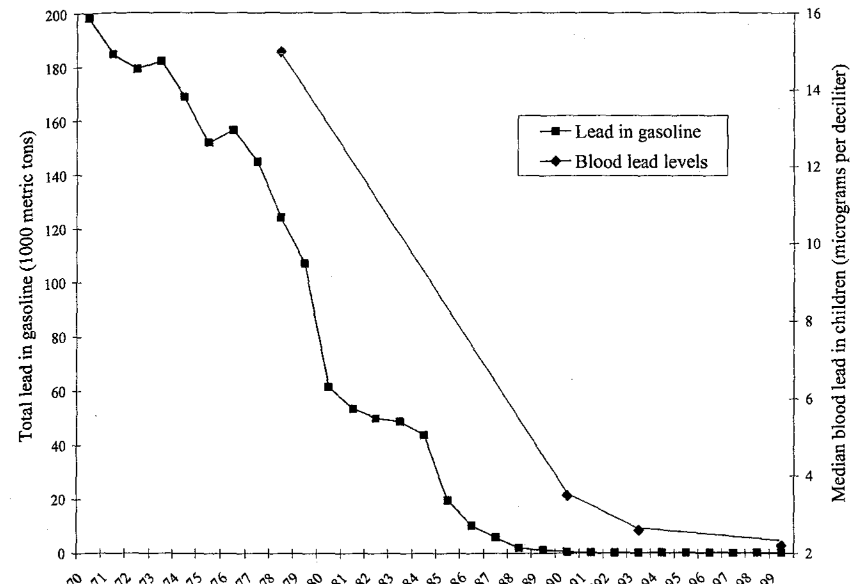

Figure 7.2. Total Lead in Gasoline and Blood Lead Levels over Time
Source: Total lead usage based on *Trends in Petroleum Fuels* (U.S. Department of Energy 1996), U.S. EPA lead program reports, and *Petroleum Marketing Monthly*. Blood lead levels from *America's Children and the Environment* (U.S. Environmental Protection Agency 2003).

changed the basis of the lead regulations to a standard that specifically limited the allowable content of lead in leaded gasoline to a quarterly average of 1.1 grams per leaded gallon (gplg). Very small refineries faced less stringent standards for a short time until 1983.

From 1983 to 1985, the EPA conducted an extensive cost-benefit analysis of a dramatic reduction in the lead standard to 0.1 gplg by 1988. The decision to consider tightening the lead standard so dramatically came in light of new scientific studies that linked two sorts of health problems directly to the ingestion of lead from fuel emissions. The first negative effect associated with lead, identified by the Centers for Disease Control and other health agencies, was mental retardation and in some cases death, especially in the case of young children. The second negative effect linked lead to elevated blood pressure, at least in middle-aged adults. Even without factoring in the blood pressure effects of lead, cost-benefit analysis unambiguously suggested the desirability of a substantial tightening of the standards. Later we cover the particulars of this analysis. Figure 7.2 illustrates the strong connection between gasoline lead and lead levels in children's blood.

The analysis suggested not only that a goal of 0.1 gplg by 1988 was feasible but that an even tighter standard might be achieved, partly because large refiners had already acquired the technology to reduce lead below the standards (Nichols 1997). In August 1984, the agency proposed a reduction of lead to 0.1 gplg by January 1, 1986. However, it was understood that some refineries might not be able to achieve this so quickly, so the agency also considered a more gradual phasedown, involving banking, that would reach 0.1 gplg by January 1, 1988. The proposal also hinted that the agency was considering a total ban on lead, but only in the long run. Thus, during 1985, the standard was reduced to 0.5 gplg, and beginning in 1986, the allowable content of lead in leaded gasoline was reduced to 0.1 gplg.

The phasedown received widespread support from the public as well as from environmentalists, the medical community, and the Office of Management and Budget, which had to review the regulations before they could be enacted. By this time, even the refiners, for the most part, accepted the reasons for removing lead from gas, though some obviously expressed reservations about the proposed timeline. Only the lead additive manufacturers and small refineries remained opposed.

To ease the transition for refineries, the 1982 regulations also permitted both trading and banking of lead permits through a system of "interrefinery averaging." Trading of lead credits among refineries was allowed from late 1982 through the end of 1987. Banking was allowed during 1985–87. Beginning in 1988, the EPA reimposed a performance standard of 0.1 gplg on individual refineries. Lead was banned as a fuel additive in the United States beginning in 1996. Figure 7.3 shows the decline over time in the lead content of leaded gasoline in the United States. Refer to

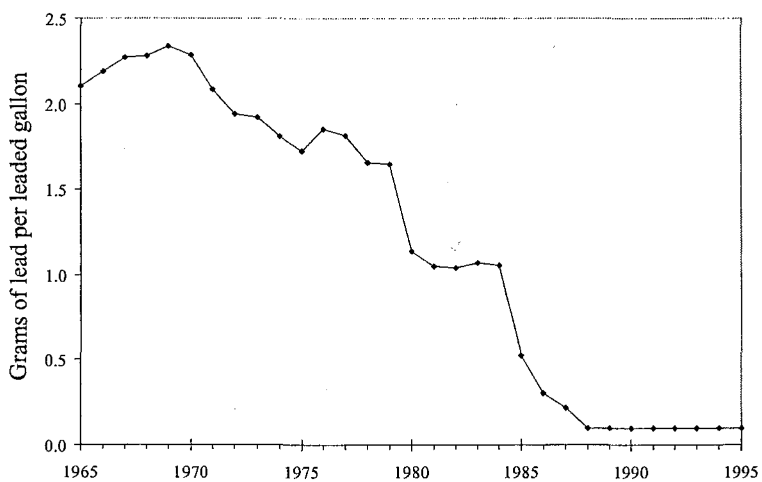

Figure 7.3. Lead Content in Leaded Gasoline (U.S. Average)
Source: Trends in Petroleum Fuels (U.S. Department of Energy 1996), and U.S. EPA lead program reports. See Kerr and Newell (2003).

Table 7.2 Small Refinery Standards for Lead Phasedown

Deadline	Standard (gpg)	Gasoline Production in Prior Year (bpd)	Definition of Small Refinery
October 1, 1979	2.65 (pooled)	Up to 5,000	50,000 bpd or less crude oil throughput capacity and owned by a company with 137,500 bpd or less total capacity
	2.15 (pooled)	5,001 to 10,000	
	1.65 (pooled)	10,001 to 15,000	
	1.30 (pooled)	15,001 to 20,000	
	0.80 (pooled)	20,001 and over	
November 1, 1982	2.65 (pooled)	Up to 5,000	10,000 bpd or less gasoline production and owned by a company with 70,000 bpd or less total gasoline production
	2.15 (pooled)	5,001 to 10,000	
July 1, 1983 and after	Same as other refineries		

Source: U.S. Code of Federal Regulations, 1996.
Note: gpg = grams of lead per gallon; bpd = barrels per day.

table 7.1 for a summary of the phasedown timeline and table 7.2 for standards for small refineries.

Constraints on the amount of lead that could be used to boost octane increased the demand for more expensive substitute sources of octane. There are two basic approaches to reducing the need for lead. One is the use of other octane-enhancing additives, such as MTBE (methyl tertiary-butyl ether). These are more expensive than lead and provide only a part of the long-term solution. Additives including MTBE provided about one-third of the octane lost due to the removal of lead in the final phasedown. Another approach is to increase refineries' ability to produce high-octane gasoline components through process changes (primarily reforming and isomerization). In the short run, existing equipment can be run more intensively to increase octane production, but eventually new investment is required. Isomerization provided around 40 percent of additional octane requirements, and alkylation, catalytic cracking, and reforming together provided most of the remaining 30 percent of lost octane. A refinery can also adjust somewhat by altering the type of crude oil it purchases, by buying intermediate products with higher octane content, or by changing its output mix to one requiring less octane.

The Mechanics of Lead Trading and Banking

Until 1982, the EPA took a prescriptive approach to regulating lead, based on technology standards and individually binding refinery performance standards for lead content. However, the agency realized by the early 1980s that this policy was causing small refiners substantial difficulty in meeting the standards on time. Smaller refineries faced higher costs of complying with the lead phasedown because they typically lacked the more sophisticated processing equipment needed to replace lost octane (e.g., reformers, alkylation). The lack of such equipment also increased the costs of installing new technologies, such as isomerization. As mentioned, small refineries were concurrently facing the loss of favorable treatment under the petroleum allocation program, which increased their cries for regulatory relief.

At the same time, several large firms had already succeeded in implementing technology that could remove more lead from their gasoline than required by the regulations, at a cost lower than that faced by small refineries. Although the vast majority of the refining industry was initially united in its support of rescinding the lead regulations, several of the larger firms realized—given they were already making compliance investments—that it was in their competitive interest to keep the regulations and remove the exemptions for small refineries.

With the release of dramatic new health evidence on the health risks of lead by the Centers for Disease Control in 1982, the Reagan administration and the EPA found they needed to quickly find an alternative to their plan for rescission. The lead trading program, which had been floated earlier by EPA analysts but had met with little support, became the instrument for reconciling this political dilemma. Lead was controlled, refineries with excess octane capacity were provided a means by which they could sell excess lead credits, small refineries were provided with significant flexibility relative to uniform standards, and the administration was able to save some face by promoting a policy that was in keeping with the market-based perspective of the Task Force on Regulatory Relief.

Also, the fact that the EPA planned to keep lowering the standards over time compounded the refiners' problem of high abatement costs, because the cost of removing an increment of lead from gasoline increased as more lead was removed, also raising issues of optimal timing of abatement investments. The solution to this issue was the banking program. The banking option was introduced at the beginning of 1985 and ended with the trading rights program at the end of 1986, although refiners were able to use their banked rights through 1987.

The new marketable permit system allowed for interrefinery lead averaging, whereby some refiners could produce higher concentrations than others, as long as the average across refineries met the agency's standard. This system alleviated at least some of the financial burden on many small firms. It also allowed the entire refining industry a measure of flexibility in allocating the reduction among its firms and in allocating investments over time, resulting in a more cost-effective reduction. The underlying premise was that the EPA should involve itself as little as possible in the trading and instead allow the marketplace itself to develop the system.

The regulations presented this scheme as interrefinery averaging and left the logistics of trading up to the refineries. Interrefinery averaging allowed all gasoline refineries and importers, whether owned by the same refiner or not, to average lead usage over a calendar quarter through a process called constructive allocation. Constructive allocation allowed refiners to comply with the applicable lead content standard by allocating actual lead usage "in any manner agreed upon by the refiners"—so long as average lead usage over the quarter did not surpass the applicable standard (e.g., 1.1, 0.5, or 0.1 gplg). Refineries or importers engaging in interrefinery averaging were free to carry out constructive allocation through whatever means they saw fit, including trades and negotiations, both monetary and otherwise. Because interrefinery averaging was offered as an alternative to individual refinery compliance, only those refineries that found this alternative beneficial would use it.

Under the basic lead content regulations, refineries were required to report quarterly on the quantity of leaded and unleaded gasoline they produced and quantities of lead used. Specifically, refineries engaging in interrefinery averaging needed to provide the following information:

- Total grams of lead that the reporting refinery allocated (sold) to other refineries, and the names and addresses of such other refineries (A);
- Total grams of lead that the reporting refinery was allocated (bought) from other refineries, and the names and addresses of such other refineries (B);
- Total grams of lead "constructively used" by reporting refinery (C = actual lead usage—A + B);
- "Constructive average" lead content of each gallon of leaded gasoline produced by the reporting refinery during the compliance period (C / total gallons produced); and
- If compliance was demonstrated through averaging with more than one other refiner, supporting documentation showing that all parties agreed to the constructive allocation.

One implication of this averaging approach, highlighted by the last bullet and discussed further shortly, is that the documentation necessary to demonstrate and monitor compliance becomes very complex as the number of parties engaged in transactions with one another increases.

The second market-based component of the lead phasedown was a banking scheme introduced in 1985 that was intended to offer a buffer for refineries facing the significant lead content decreases slated for 1986. This modification provided temporal flexibility to refiners in addition to the interrefinery trading flexibility established in 1982. Under the banking mechanism, refiners who used less than 0.5 gplg but more than 0.1 gplg of lead in leaded gas in 1985 were permitted to use this same amount of lead in gasoline between 1985 and 1988, in addition to the lead permits issued and bought during that time period. Production of leaded gas with less than 0.1 gplg did not generate additional credits. Thus, the banking regulations extended a refinery's time frame for compliance with the 0.1 gplg standard.

The 1985 regulations also eliminated the interrefinery averaging provisions of the 1982 regulations as of January 1, 1986, although refiners were permitted to buy credits from other refiners' banks until the end of 1987. The EPA was concerned that the interrefinery trading provisions encouraged the production of leaded gasoline with only trace amounts of lead. The agency believed that engines designed to use leaded gas required at least 0.1 gplg to operate properly and wanted to eliminate any incentive to generate lead credits by producing leaded gas with concentrations below this threshold. Thus, with the end of the banking regulation in 1988, the lead trading program was completed.

The next section presents information on projected estimates of the effects of the program prior to its implementation. Then we present ex post evidence on the efficiency and effectiveness of the program measured after the policy had run its course. We draw overall conclusions and lessons for future policy in the final section.

PROJECTED EFFECTS OF THE MARKET-BASED LEAD PHASEDOWN

Ex ante estimates of the effects of the lead trading program were derived primarily from an EPA regulatory-impact analysis (RIA) performed between 1984 and 1985, which predicted the costs and benefits of bringing the lead standard down to 0.1 gplg by the beginning of 1986.[4] Refer to table 7.3 for physical measures of the proposal's benefits and table 7.4 for its monetized costs and benefits.

Projected Benefits

The benefits associated with the proposed rule fall into four categories: children's health, health and environmental effects from nonlead pollutants, vehicle maintenance and fuel economy effects, and blood pressure effects (Nichols 1997). The first benefit, children's health effects related to lead, was quantified in monetary terms as the avoided costs of medical treatment and remedial education that would be incurred if existing (1982) standards (1.1 gplg) remained in effect. The avoided medical costs were estimated at $900 (in 1983$) per child with blood-lead levels above 25 micrograms per deciliter ($\mu g/dl$). The estimates for compensatory education averaged about $2,600 per child with blood levels above the same threshold. The total benefits in this category ranged from about $600 million in 1986 to $350 million in 1992 (U.S. EPA 1985a). (Note that all monetary figures are in 1983 dollars.) The benefits tend to fall over time because the baseline against which the regulatory impact is measured

Table 7.3 Physical Measures of Estimated Benefits of Final Lead Phasedown Rule

	Year			
Estimated Effects	1985	1986	1987	1988
Reductions in children above 25 micrograms/dl blood lead (1,000s)	64	171	156	149
Reduced emissions of conventional pollutants (1,000s ton)				
HC	0	244	242	242
NO_x	0	75	95	95
CO	0	1,692	1,691	1,698
Reduced blood-pressure effects in males age 40–59				
Hypertension (1000s)	547	1,796	1,718	1,641
Myocardial infarctions	1,550	5,323	5,126	4,926
Strokes	324	1,109	1,068	1,026
Deaths	1,497	5,134	4,492	4,750

Source: Nichols (1985, table 1) and (U.S. EPA 1985a).

Table 7.4 Estimated Monetized Costs and Benefits of Final Lead Phasedown Rule (in millions $1983)

	Year			
Estimated Effects	1985	1986	1987	1988
Monetized benefits				
Lead-related effects in children	223	600	547	502
Blood pressure–related (males, 40–59)	1,725	5,897	5,675	5,447
Conventional pollutants	0	222	222	224
Maintenance and fuel economy	137	1,101	1,029	931
Total monetized benefits	2,084	7,821	7,474	7,105
Costs				
Increased refining costs	96	608	558	532
Net benefits				
Including blood pressure	1,988	7,213	6,916	6,573
Excluding blood pressure	264	1,316	1,241	1,125

Source: U.S. EPA 1985a, Table VIII-7c.

includes the transition to an unleaded car fleet. Thus, there are fewer cars using leaded gasoline over time, which lessens the impact of a reduction in the lead content of leaded fuel.

The second benefit, health and environmental effects related to other pollutants, were quantified in two different ways. The first method was a direct valuation: The EPA estimated the physiological responses to various doses and estimated and assigned dollar values to health and welfare endpoints. However, these values were deemed to be highly uncertain and did not include any values for some potentially important impacts (Nichols 1997). For example, the study considered only the effects of reductions in HC and NO_x, and omitted CO as a factor. Internal EPA offices had argued those effects were too uncertain to include in the analysis. The second method was an implicit valuation of the reductions, in which the EPA used the forgone expenses of repairing damaged catalytic converters to indicate a minimum value of preventing the pollution. Catalytic converters faced damage when individuals misfueled unleaded cars with leaded gas. The final estimates were based on an average of the two methods and totaled $222 million in 1986 (U.S. EPA 1985a).

The EPA also estimated benefits in the form of reduced maintenance costs and increased fuel economy. It estimated the maintenance benefits at about $0.0017 per vehicle mile, or an aggregate of about $900 million in 1986, along with additional fuel economy benefits of about $200 million per year (U.S. EPA 1985a).

Finally, the EPA included limited estimates of the proposal's effects on blood pressure. The RIA predicted that the policy would reduce the number of middle-aged men with hypertension by about 1.8 million in 1986 at a value of $220 per year per case of hypertension avoided (U.S. EPA 1985a). Also, the reduced hypertension would mitigate the likelihood of other cardiovascular afflictions. Based on a number of epidemiological studies, the estimates yielded benefits of $60,000 per heart attack and $40,000 per stroke avoided. Added to the benefits of reduced mortality rates, these figures result in total blood pressure–related benefits of over $5 billion each year from 1986 to 1988.

Projected Costs

The estimated costs of the rule include the cost to refiners of additional processing or the use of other additives to replace the fuel octane previously supplied by lead plus the lost consumer surplus due to higher gasoline prices. The results took into account the costs saved through the banking program. The additional processing costs (primarily from reforming or isomerization) totaled less than $100 million for the second half of 1985, under the 0.5 gplg standard (U.S. EPA 1985a). Under the 0.1 gplg rule, the projected costs fell over time from $608 million in 1986 to $441 million in 1992 due to projected declines in the demand for leaded gasoline in the absence of the new rule (Nichols 1997).

The RIA further predicted that refiners would achieve substantial cost savings through the innovative banking program. It estimated that refiners would together bank between 7.0 and 9.1 billion grams of lead in 1985, which would reduce the present value costs of the 0.1 gplg rule by between $173 and $226 million, or about 16 to 20 percent, depending on when refiners began banking (U.S. EPA 1985a). In actuality, refineries began banking immediately on being permitted to do so, in line with the higher cost-saving estimate. The RIA did not estimate the cost savings from allowing trading relative to a more prescriptive, uniform standards alternative.

At the time of the RIA, the average retail price of unleaded was about $0.07 per gallon higher than that of leaded. However, all other measures of the marginal value of lead in gasoline (i.e., wholesale prices, lead permit prices, and lead shadow prices) indicated the significantly narrower differential of less than $0.02 per gallon. The EPA believed the $0.07 figure was mainly a result of marketing strategies and that the $0.02 figure was more representative of real resource costs (Nichols 1997).

As an addendum to the RIA, the EPA also estimated the benefits and costs of a complete ban on lead in 1988—that is, moving from 0.1 gplg to no leaded fuel. A ban on leaded gasoline, the agency reported, would further reduce the number of children with toxic blood-lead levels by about 7,000 in 1988, prevent up to 100,000 more cases of hypertension among middle-aged men, and reduce heart-related fatalities by about 400 (U.S. EPA 1985b). The incremental cost to refiners of a complete ban was predicted to be $149 million, and the incremental benefits were placed between $193 million and $635 million (U.S. EPA 1985b). These results clearly provided justification for a ban on gasoline, but the EPA chose to wait to minimize the risk of damage to older engines (Nichols 1997). A ban was enacted in 1996, but by then virtually all lead had already been eliminated.

EX POST EVALUATION OF THE PHASEDOWN

In this section, we assess the performance of the lead trading system along several dimensions, including its overall effectiveness, static and dynamic efficiency, revelation of costs, and distributional effects that include environmental hot spots, regulatory and administrative burden, and monitoring requirements. We have made use of all information on program impacts that was available to us, although in some cases that information is admittedly incomplete.

Overall Effectiveness

Probably the most useful measure of the phasedown's effectiveness is the extent to which the regulations accelerated the reductions in lead consumption that were already being made thanks to the fleet turnover. The phasedown program, along with the turnover effects, achieved in 1981 what the fleet turnover alone would not have achieved until around 1987. From the start of the phasedown in 1979 to the completion of the marketable permit program in 1988, the regulations imposed on the refineries accounted for about 36 percent of the total gasoline lead reduction during that time, amounting to over half a million tons of lead that would otherwise have been emitted (Holley and Anderson 1989). The use of banking in the program further accelerated the lead reductions relative to what they would have been in the absence of banking.[5] Figure 7.2

illustrates the decline in total gasoline lead from 1970 onward, along with the concurrent decline in lead levels in the blood of children. The decline in blood lead levels is due largely to the phasing out of lead in gasoline between 1973 and 1995, but also to the reduction in the number of homes with lead-based paint (U.S. EPA 2003).

Static Efficiency

The static efficiency of the marketable lead permit program can be measured by the cost savings it achieved—that is, the difference in the costs to abate the same amount of lead under uniform standards versus the tradable permit policy. Unfortunately, the EPA collected no comprehensive data on permit prices, so this amount can only be estimated. Anecdotal evidence suggests that prebanking permit prices (i.e., under the 1.1 gplg standard) were typically under $0.01 per gram, and then rose significantly to $0.02–$0.05 per gram after the regulations were tightened in 1985 (Hahn and Hester 1989). Based on these figures, Hahn and Hester (1989) estimate that the marketable permit program saved hundreds of millions of dollars in abatement costs. Unfortunately, there are no other available estimates of the ex post cost savings from the program.

There are other indications that the tradable permit program allowed for lower costs than comparable uniform standards, most notably the fact that permits were traded at all. Assuming that refineries were not systematically shooting themselves in the foot, it follows logically that they traded permits because doing so saved money. Low-cost firms were able to abate a portion of their lead and sell the corresponding permits to high-cost refineries, realizing a net gain in revenues in the process. The high-cost refineries that bought the permits did so because the permit price was less than the cost for them to reduce the corresponding lead, allowing them to save money. Indeed, the lead rights market was very active in terms of volume of permits traded, and this activity increased as the trading program matured. Lead rights traded as a percent of all lead produced increased from around 7 percent in the third quarter of 1983 to over 50 percent in the second quarter of 1987 (Hahn and Hester 1989).

In addition, the mechanics of the marketable permit policy were such that transaction costs appear to have done little to inhibit permit trading (Kerr and Maré 1997). These costs could arise from firms having to establish their marginal value of lead, collect information on permit prices and find trading partners, collect information on the validity of the permits to be traded, negotiate permit quantities or prices (or both), and having to release potentially sensitive business information in the process of trading. Selling permits also meant parting with their option value, which would be important in the event of abatement cost shocks (Kerr and Maré 1997). This may imply that transaction costs are likely to be more burdensome for small refiners, as they lack the scale and resources that would keep these costs relatively low. Using econometric methods, Kerr and Maré (1997) estimate that more than 80 percent (and probably closer

to 90 percent) of efficiency was achieved in the lead trading program—that is, close to 90 percent of trades that would have occurred absent any transaction costs still did occur with those costs, all else being equal. They find an efficiency loss of only 10 percent, owing to a failure to trade as a result of transaction costs.

Dynamic Efficiency

The banking program offered additional cost savings to participating refiners. This program allowed refiners to lower their overall costs of abatement by "smoothing out" their emissions over time. This was an important component for many firms, as their marginal cost schedules increased rapidly with increasing lead restrictions. This situation is evidenced by the fact that both large and small refiners produced lead in concentrations below the standards early in 1985, the year banking was introduced, implying that they were banking the difference. Both groups then exceeded the tighter standards in 1986 and 1987, when they used the saved permits to ease their transition to tighter standards. The EPA's ex ante projection that banking would save upward of $226 million probably turned out to be an underestimate, as the agency's figures assumed that 9.1 billion grams of lead would be banked, whereas 10.6 billion grams were actually banked, starting at the earliest possible date (Hahn and Hester 1989). There seems no doubt that the banking program saved hundreds of millions of dollars.

Kerr and Newell (2003) address dynamic efficiency in the context of the U.S. lead phasedown through their analysis of octane-enhancing technology (i.e., isomerization) adoption to replace lead. They investigated the influence of refinery characteristics (i.e., size of refineries or firms, technological sophistication), technology costs, and most important, regulatory variables, including regulatory stringency and form (e.g., tradable permits versus individually binding performance standards). They found a large positive response of lead-reducing technology adoption to increased regulatory stringency, indicating that the regulations were effective in providing incentives for dynamic changes in technology. In addition, they found a pattern of technology adoption across firms that is consistent with an economic response to market incentives, plant characteristics, and alternative policies.

Economic theory suggests that tradable permit programs create an incentive for more efficient technology adoption than uniform performance or technology standards—that is, they provide greater incentives for reducing abatement costs, including dynamically over time. Intuitively, the tradable permit system encourages all plants to take action until their marginal costs equal the permit price. Taking the price of permits as given, plants that have marginal costs below the market permit price (sellers) can capture even greater profits under the permit system (compared to a uniform standard) by adopting new technology that further reduces costs. This is in contrast to plants that have marginal costs above the permit price (buyers), for whom buying permits is a less costly option than installing the new technology. The incentives to adopt would thus be lower for buyers under the permit system than under uniform standards, because they could buy permits rather than being forced to self-comply with relatively expensive reductions (Malueg 1989).

Thus the tradable permit system provides incentives for more efficient adoption, but it can lower adoption incentives for some plants with high compliance costs.[6] Under a nontradable performance standard, such opportunities for flexibility do not exist to the same degree. If plants face individually binding standards, they will be forced to take individual action—such as technology adoption—regardless of the cost, with the resultant inefficiency reflected in a divergence across plants in the marginal costs of pollution control.

As suggested by theory, Kerr and Newell found a significant divergence in the adoption behavior of refineries with low versus high compliance costs under the tradable permit program. The positive differential in the adoption propensity of expected permit sellers (i.e., low-cost refineries) relative to expected permit buyers (i.e., high-cost refineries) was significantly greater under market-based lead regulation compared to under individually binding performance standards. Overall, their results are consistent with the finding that the tradable permit system provided more efficient incentives for technology adoption decisions.

To be clear, however, that research did not explore whether the market-based program resulted in *greater* technology adoption overall or greater incentives for new innovations. It is entirely possible, for instance, that a rigid uniform standard could lead to greater technology adoption because it forces all firms to individually comply. From the perspective of economic efficiency, however, the goal is not more technology adoption and innovations per se but minimization of the total costs over time of achieving a desired set of environmental and other objectives. From that perspective, the lead phasedown seems to have performed quite well.

Distributional Effects

Many very small refineries, with the highest cost structures, were inevitably eliminated from the market by the phasedown and other economic and regulatory forces, and the ones that did survive were more likely to become permit buyers than sellers. Empirical evidence, in fact, shows this to be true. Hahn and Hester (1989) report that net transfers of lead rights tended to be from large refiners to small ones (large refiners tending to have lower abatement costs than small ones). Small refiners had to purchase permits from large ones, incurring a transfer of private revenue from small refiners to large ones. Nevertheless, relative to a uniform performance standard, small refineries were better off under the tradable permit policy.

Environmental hot spots and spikes were not a significant concern in the case of lead emissions from automobile exhaust. The pollution is created through gasoline consumption, not production, and there is little relationship between the location of refineries and automobile exhaust across the country. Even if there existed a case where a local region was predominantly served by small refineries producing gasoline with relatively high lead content, it is not clear that a comparable standards-based policy would not have granted exemptions to small refineries, as they had done in the past. Thus prescriptive instruments had no clear advantage over market-based incentives with respect to hot spots and spikes of atmospheric lead from gasoline.

Monitoring and Administrative Burden

The EPA delegated the responsibilities of data collection and assimilation to the refiners themselves, which then reported their figures to the agency. The agency set up a computer system, which processed refinery reports to detect inconsistencies and probable inaccuracies. Participating refiners had to report their quarterly lead rights transactions, including trade volumes and the names of trading partners; refiners who used the banking option were also required to report deposits and withdrawals. All of the information required by the reports was readily available to the refiners, so the added costs of monitoring were relatively low (Holley and Anderson 1989). Figures on lead usage were checked against sales figures of additive suppliers. Gasoline volume was not as easily monitored as lead, however, and more enforcement cases involved misreported output than misreported lead use. Although the marketable permit program may have required monitoring a greater quantity and variety of information than a prescriptive policy would have, the collection of this information was fairly straightforward and inexpensive. The actual design of the rule was fairly simple: The agency had only to establish the desired lead concentration and review refiners' reports regarding their lead usage, gasoline production, and any averaging.

Nonetheless, the administrative burden of the lead permit program on the EPA was considerable relative to what it might have been if the system had been based on the allocation and trading of discrete emission units (e.g., grams of lead), such as in the U.S. SO_2 permit system. Rather, the system was based on averaging among refineries of lead content per unit of output, which meant that lead credits could in effect be created by producing gasoline. Had the system been based on the allocation of discrete emission units (e.g., grams of lead), there would not have been an ability to create lead credits by increasing gasoline production. This also might not have been a significant issue if the EPA had more narrowly or more carefully drawn the boundaries on participants in the program. But it did not, which gave rise to the entry of a large number of unexpected small entities who were primarily in the business of creating lead credits.

In the end, the output-based averaging basis of the marketable permit system created substantial monitoring and enforcement problems for the EPA (Holley and Anderson 1989).

The most significant problem was related to the unexpected creation of a quasi-industry of alcohol blenders, which were mainly large service stations that added alcohol to leaded fuel. In doing so, these blenders lowered the average lead content of the aggregate volume of fuel, thereby generating lead credits that could be sold in the permit market to other refineries. This approach to compliance was made possible by the fact that the lead performance standard was measured as a ratio to output, and there were few restrictions on who could participate in lead trading.[7] By the beginning of 1985, there were 300 blenders reporting permit trades, and within a year that figure had doubled. This was a significant increase on top of the expected reports from about 250 traditional refineries. The EPA's rules considered the blenders to be in effect refineries, and the agency's enforcement and monitoring mechanisms treated them as such. Thus, the unexpected inflow of 600 additional lead production/trading reports significantly slowed the monitoring and enforcement processes.[8] Although it was the output-based nature of the program that gave rise to incentives for these participants to enter, the problem might have been controlled by limiting the universe of potential participants, as with the Title IV NO_x program, which also includes an averaging provision but is limited to a clear set of electricity generation units.

To make matters worse, the reporting blenders were relatively disorganized, and their reports to the EPA were replete with errors, causing problems with the agency's report-processing system. During the time that the reports were being manually processed, invalid permits might have been sold or even resold, and financially unstable market participants might have disappeared before their violations were ever detected (Holley and Anderson 1989).

Detection of such problems is likely to have been inhibited by the documentation necessitated by the averaging approach, because demonstrating and monitoring compliance becomes increasingly complex as the number of parties engaged in transactions with one another increases. That is, if two refineries average only with one another, it is reasonably straightforward to demonstrate that the average standard is met. But if either or both of these refineries averages with other refineries as well, the lead input and gasoline output of all the refineries is necessary to demonstrate compliance of any of the parties. And if any of these elements is found to be incorrect, the compliance of all parties is potentially called into question, and it may not be exactly clear who has legitimate versus illegitimate lead credits. Layer on top of this the ability to bank and it quickly becomes clear that problems could emerge, especially if some parties are short-lived or are careless in their reporting. Individually binding refinery standards would likely not have experienced many of these enforcement problems.

Independent of the blender problem, the lead permit program gave rise to a number of other administrative and enforcement issues. The most common violations were:

- Self-reported excess lead usage;
- Failure to report regulated activities as required;
- Incorrect report indicating compliance, but where the average lead usage per gallon is actually above the standard due to using more lead or producing less gasoline than was reported (either of these raises lead content per gallon);
- Failure to include shipments of imported gasoline in reports;
- Falsifying banked rights;
- Changes in accounting systems resulting in the disappearance of lead that should have been accounted for; and
- Claiming lead rights based on fictitious production.

Because lead credits were fully fungible, and because false credits could be traded several times before being discovered by the EPA, tracing invalid rights to their source proved very difficult (Holley and Anderson 1989). The EPA had expected most of the violations to be committed by a small number of large refiners and planned its enforcement policies accordingly. But it turned out that most of the violations were in fact committed by a fairly large number of small refiners with small amounts of lead rights to which the existing enforcement mechanics were less easily applied.

In 1985, with the increased stringency of the standard and the introduction of the banking program, the EPA therefore began to perform audits of suspect refineries. Up to this point, the agency had detected violations through inconsistencies and inaccuracies in refinery reports, resulting in seventy-one notices of violation with proposed penalties totaling $17.8 million through 1986 (Holley and Anderson 1989). After the agency started auditing, it issued seventeen notices of violation in 1987 alone, with proposed penalties topping $54 million. In some settlement cases, refiners were presented with the option of retiring a portion of their lead rights instead of paying direct financial penalties. Refiners who chose this option relinquished some 150 million grams of lead pollution rights (assuming those permits would have been used), representing an estimated value of about $40 million in 1983 dollars (Holley and Anderson 1989).

Holley and Anderson suggest that the relatively high level of enforcement activity through audits brought about a reduction in noncompliance. They point to the trend that as the EPA devoted an increasing amount of resources to audits and as the number of audits performed increased, the number of noncompliance cases decreased. But despite the agency's success in detecting many violations through audits, it was partly the flexible nature of the agency's marketable permit approach that increased the likelihood of administrative difficulties and violations. It is possible much of this could have been avoided, however, by establishing a trading system with fixed rather than output-based allocations, or by simply limiting the universe of market participants to traditional refiners. On the other hand, such restrictions can limit the potential for unforeseen opportunities for low-cost mitigation. In addition, one of the reasons the definition of a refinery was written so broadly was apparently to prevent loopholes.

LESSONS LEARNED FROM THE LEAD PHASEDOWN

One can draw several lessons from the U.S. experience with phasing the lead out of gasoline. Most important, the program demonstrated that a tradable permit system could be effective in meeting its environmental objectives. The phasedown from 1979 to 1988 accelerated the virtual elimination of lead in gasoline by at least a few years, reducing by 1988 an additional half-million tons over what the fleet turnover would have achieved. The banking component further demonstrated that environmental objectives can be met more quickly under a permit system with banking than if banking is not allowed.

The marketable lead permit system also established that a given environmental target could be met more cost-effectively through trading and banking, saving hundreds of millions of dollars relative to comparable uniform standards not allowing trading or banking. The banking program itself saved over $225 million because it allowed for a more cost-effective allocation of technology investment within the refining industry. The lead phasedown experience also showed that transaction costs do not necessarily cripple tradable permit programs, with estimates suggesting that transaction costs brought about only a modest reduction in the efficiency of the market-based program.

Evidence also suggests that the market-based nature of the lead permit program provided incentives for more efficient adoption of new lead-removing technology, relative to a uniform standard. The pattern of technology adoption under this program was consistent with an economic response to market incentives and plant characteristics. As theory contends, there was a significant divergence in the adoption behavior of refineries with low versus high compliance costs. Expected permit sellers (i.e., low-cost refineries) significantly increased their adoption of new technology relative to expected permit buyers (i.e., high-cost refineries) under market-based lead regulation compared to under individually binding performance standards.

Distributional effects are always high in political importance, with the lead phasedown demonstrating that the use of market-based instruments can be consistent with addressing distributional concerns. It is likely that the lead permit program was actually more responsive to the high costs of small refiners than comparable uniform standards would have been. Another key worry about tradable permit programs, environmental hot spots, was shown not to be a significant concern in this case, although it certainly could be with some localized pollutants.

Unfortunately, basing the lead program on a system of averaging lead per unit output, without sufficient constraints on program participation, increased the incidence of both intentional and unintentional violations, especially on the part of smaller refiners and fuel blenders. This added an unexpected administrative burden to the EPA's existing monitoring and enforcement costs and in some cases was associated with outright fraud. Individually binding performance standards would likely not have had these problems, although the problem could likely have been avoided by basing the program on the allocation of discrete emission units or by more carefully restricting the ability of entities to participate in the program. On the other hand, there was likely to have been efficiency advantages to the participation of unexpected program participants, which serves as a reminder that one of the advantages of flexible, incentive-based programs is that they provide opportunities and incentives for unanticipated means of cost-effective compliance. In the end, the introduction of an effective audit and enforcement programs was crucial.

Overall, the benefits of the U.S. lead phasedown are likely to have outweighed its costs ten to one, with lead trading and banking significantly lowering those costs. But the lead phasedown did not involve only a tradable permit system. It also relied heavily on the transition to a new unleaded car fleet, mandated by the requirement to use unleaded fuel in cars with catalytic converters. A similar story can probably be told for most major environmental problems, where technology standards, performance standards, and other approaches are used in tandem with economic incentives.

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NOTES

1. Octane is a characteristic of fuel components that improves the performance of engines by preventing fuel from combusting prematurely in the engine. The availability of high-octane fuel allows more powerful engines to be built. Cars will not operate efficiently with a lower octane fuel than that for which they were designed. In addition, some older cars may need more than a minimum level of lead (less than 0.1 grams of lead per gallon) to prevent a problem called valve seat recession.

2. As described in Nichols (1997), lead emissions from gasoline are linked to elevated blood-lead levels, which are associated with significant health effects, especially in the case of young children. In sufficiently high doses, lead can cause severe retardation and sometimes even death. Moderate to high blood-lead levels are sufficient to negatively effect cognitive performance in children, though the magnitude of cognitive effects due to low-level lead exposure are still disputed. In addition, studies have suggested that elevated blood-lead levels are associated with increased blood pressure and hypertension rates in middle-aged adults. Lead

in gasoline can also raise maintenance costs by causing salt corrosion in an automobile's engine and exhaust system, causing damage to the muffler, spark plugs, and other components.

3. It is relevant to note that this coincides in time with the removal by the Reagan administration in 1981 of remaining petroleum price and allocation controls, which had originally been established during the 1970s in response to the Arab oil embargo. Small refineries had received favorable treatment under these programs and in response the number of refineries had swelled from 268 in 1973 to 324 in 1981, with the bulk of these refineries being small (U.S. EIA 1990). With removal of the allocation controls, the number of refineries fell back to pre-embargo levels within two years.

4. After an initial analysis of achieving the standard by 1988, in which the benefits easily outweighed the costs, the EPA proposed the even closer deadline of January 1, 1986. The following presents estimates from the RIA for the later proposal.

5. Although it is true that one could imagine a traditional regulatory standard that simply forced reductions earlier to coincide with the pattern of reductions under the banking provisions, this is not the appropriate counterfactual in this case. When the proposed regulations for accelerating the phasedown were issued, the banking provision was treated as an independent option, treated separately from the averaging scheme and the phasedown schedule. The final banking rule was in fact issued as a separate regulation.

6. Whether any of these policies provide incentives for fully efficient technology adoption depends on a comparison with the social benefits of technology adoption and the usual weighing of marginal social costs and benefits.

7. *See* Helfand (1991) for an assessment of the incentives given by alternative designs of regulatory standards.

8. On the other hand, there was likely to have been efficiency advantages to the participation of blenders in lead compliance, because they apparently offered a cost-effective means to reducing lead content. This serves as a reminder that one of the advantages of flexible, incentive-based programs is that they provide opportunities and incentives for unanticipated means of cost-effective compliance.

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