The Market-based Lead Phasedown

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Abstract

The U.S. lead phasedown was effective in meeting its environmental objectives, and did so more quickly with the allowance of permit banking. The marketable lead permit system was highly cost-effective, saving hundreds of millions of dollars relative to comparable policies not allowing trading or banking. Estimates suggest that transaction costs brought about only a modest reduction in program efficiency. The market-based nature of the program also provided incentives for more efficient adoption of new lead-removing technology, relative to a uniform standard. Distributionally, it is likely that the program was actually more responsive to the cost concerns of small refiners than a similar uniform standard would have been. The flexibility of the program likely increased the amount of violations, however, and added an unexpected monitoring and enforcement burden. On the other hand, one of the efficiency advantages of the incentive-based program is that it provided opportunities for unanticipated means of cost-effective compliance.

Key Words: lead phasedown, gasoline, tradable permit, market-based policy, technology adoption

JEL Classification Numbers: Q25, Q28, Q21

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1. 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 1980's. The phasedown was accomplished in part through a tradable permit system among refineries, whereby lead credits could be exchanged and/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 in order 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, which include mental retardation and hypertension. 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.

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[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 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.

1.1 Unleaded Fuel Cars Starting with Model Year 1975

The phasedown of lead in gasoline began in 1974, when, under the authority of the Clean Air Act Amendments of 1970, the U.S. Environmental Protection Agency (EPA) introduced rules requiring the use of unleaded gasoline in new cars equipped with catalytic converters. (See a summary of the phasedown in Table 1.) The introduction of catalytic converters for control of hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO) emissions required that motorists use unleaded gasoline, because lead destroys the emissions control capacity of catalytic converters. The eventual phasedown of lead in gasoline is largely attributable to the decreasing share of leaded gasoline that resulted from the transition to a new car fleet. This transition is shown in Figure 1. To help promote the supply of unleaded gasoline and avoid misfueling, EPA also mandated that unleaded cars have specially designed fuel inlets that fit only unleaded gasoline nozzles, and that gasoline retailers offer unleaded gasoline for sale.

1.2 Phasedown of Lead in Gasoline

To further promote the production of unleaded gasoline, EPA also scheduled performance standards requiring refineries to decrease the average lead content of all gasoline (leaded and unleaded pooled) beginning in 1975, but these were postponed until 1979 through a series of regulatory adjustments. By then, studies had provided increasing evidence of the adverse effects of atmospheric lead on the IQ of children and on blood pressure in adults (U.S. EPA 1985a or b?).[2] While lead use would have eventually dwindled as the last pre-1975 cars were retired, the growing evidence of health impacts prompted an accelerated phaseout of lead in gasoline.

[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 impact negatively 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.

EPA established individual facility performance standards for refineries and a series of deadlines for compliance that took effect over several years, beginning in October 1979. The standards varied according to the size of the facility. Large refiners (those with production capacity over 50,000 barrels per day (bpd) and/or those owned or controlled by a refiner having total capacity over 137,500 bpd) were to produce a quarterly average of no more than 0.8 gram per gallon (gpg) for the first year and 0.5 gpg in the next two years. Small refiners (with capacity of up to 50,000 bpd) faced a scale of five different standards, ranging from 2.65 gpg for the smallest of the group to 0.8 gpg for the largest. It was up to the individual refiner to meet these standards in the time allotted. About 60 percent of refineries were small according to the definition. The average refinery had a capacity of about 67,000 bpd, ranging from 50,000 to 640,000.

It is important to note that the early regulation set an average lead concentration for total gasoline output, both leaded and unleaded. This 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 pre-catalyst automobiles and replacing them with new cars that required unleaded fuel.

By the early1980s, gasoline lead levels had declined about 80% as a result of both the regulations and the fleet turnover (Nichols 1997). As part of President Reagan's Task Force on Regulatory Relief, EPA considered deferring the deadlines and relaxing the standards in response to growing complaints from lead additive manufacturers (who contended the lead regulations were unnecessary because lead was on its way out anyway) and small refiners who were having difficulty complying on time. 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 (as 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 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, EPA conducted an extensive cost-benefit analysis of a dramatic reduction in the lead standard to 0.1 gplg by 1988. The analysis suggested that this goal was not only 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.[4]

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

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[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 (US EIA 1990). With removal of the allocation controls, the number of refineries fell back to pre-embargo levels within two years.

[4] The decision to tighten 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. Section 2 covers the particulars of this analysis.

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 "inter-refinery averaging." Trading of lead credits among refineries was allowed from late 1982 through the end of 1987. Banking was allowed during 1985–1987. Beginning in 1988, 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 2 shows the decline over time in the lead content of leaded gasoline in the United States. Refer to Table 1 for a summary of the phasedown timeline and Table 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% of additional octane requirements, and alkylation, catalytic cracking, and reforming together provided most of the remaining 30% 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.

1.3 The Mechanics of Lead Trading and Banking

Until 1982, 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 since 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 above, 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. While the vast majority of the refining industry was initially united in its support of rescinding the lead regulations, several of the larger firms realized that— given they were already making compliance investments— 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 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 EPA planned to keep lowering the standards over time compounded the refiners' problem of high abatement costs, since 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 inter-refinery 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 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 "inter-refinery averaging" and left the logistics of trading up to the refineries. Inter-refinery 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 inter-refinery averaging were free to carry out constructive allocation through whatever means they saw fit, including trades and negotiations, both monetary and otherwise. Because inter-refinery 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 inter-refinery 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.

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 inter-refinery 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 inter-refinery 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. EPA was concerned that the inter-refinery 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.

Section 2 presents information on projected estimates of the effects of the program prior to its implementation. Section 3 presents ex post evidence on the efficiency and effectiveness of the program measured after the policy had run its course. We draw overall conclusions in Section 4.

2. 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.[5] Refer to Table 3 for physical measures of the proposal's benefits and Table 4 for its monetized costs and benefits.

2.1 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 (μg/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 second benefit, health and environmental effects related to other pollutants, were quantified in two different ways. The first method was a direct valuation: 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 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).

EPA also estimated benefits in the form of reduced maintenance costs and increased fuel economy. It estimated the maintenance benefits at about $.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, 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.

2.2 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

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[5] 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.

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 16-20%, depending on when refiners began banking (U.S. EPA 1985a). In actuality, refineries began banking immediately upon 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. 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, 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, EPA 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, while 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 EPA chose to wait in order 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.

3. 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.

3.1 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.

3.2 Static Efficiency

The static efficiency of the marketable lead permit program can be measured by the cost savings it achieved—i.e., the difference in the costs to abate the same amount of lead under uniform standards versus the tradable permit policy. Unfortunately, EPA collected no comprehensive data on permit prices, so this amount can only be estimated. Anecdotal evidence suggests that pre-banking permit prices (i.e., under the 1.1 gplg standard) were typically under $.01 per gram, and then rose to $.02–$.05 per gram after the banking feature began (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.

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% in the third quarter of 1983 to over 50% 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 down 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%, and probably closer to 90%, of efficiency was achieved in the lead trading program—that is, close to 90% 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%, owing to a failure to trade as a result of transaction costs.

3.3 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 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. EPA’s ex ante projection that banking would save upwards 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 importantly, regulatory variables, including regulatory stringency and form (e.g., tradable permits vs. 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—that is, they provide incentives for reducing abatement costs as much as possible, including dynamically over time. Taking the price of permits as given, permit sellers (i.e., firms with relatively low abatement costs) would want to invest in technology that would lower their marginal abatement cost so that they could capture a greater surplus in selling the permits. On the other hand, refiners with relatively high abatement costs (i.e., buyers), whose technology adoption would still be insufficient to lower costs below permit prices, would have a decreased incentive to adopt because doing so would merely reduce their cost savings. The incentives to adopt would thus be lower for buyers under the permit system than under uniform standards, since 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.[6] Under a nontradable performance standard, such opportunities for flexibility do not exist to the same

[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.

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 rather 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.

3.4 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.

3.5 Monitoring and Administrative Burden

EPA delegated the responsibilities of data collection and assimilation to the refiners themselves, which then reported their figures to the agency. EPA 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.

Nonetheless, the administrative burden of the lead permit program upon EPA was considerable relative to what it might have been if the system was allowance-based rather than output-based or had more narrowly drawn the boundaries on participants in the program, such as in the U.S. SO_2 permit system. 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. But the output-based averaging basis of the marketable permit system created substantial monitoring and enforcement problems for 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. 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] While 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 NOx program.

To make matters worse, the reporting blenders were relatively disorganized and their reports to EPA were replete with errors, causing problems with the agency's report-processing computer 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).

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;

[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, as 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.

- Incorrect report indicating compliance, but where the average lead usage is actually above the standard due to using more lead than was reported or actually producing less leaded gasoline;
- Failure to include shipments of imported gasoline in reports;
- Using as blend stock in one calendar quarter materials that had been reported in the previous quarter as leaded gasoline;
- Falsifying banked rights;
- Changes in accounting systems resulting in the disappearance of lead that should have been accounted for; and
- Claiming lead rights based upon fictitious production.

Since lead credits were fully fungible, and since false credits could be traded several times before being discovered by EPA, tracing invalid rights to their source proved very difficult (Holley and Anderson 1989). 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 introduction of the banking program, EPA therefore began to perform audits of suspect refineries. Up until this point, the agency had detected violations through inconsistencies and inaccuracies in refinery reports, resulting in 71 notices of violation (NOVs) with proposed penalties totaling $17.8 million through 1986 (Holley and Anderson 1989). After the agency started auditing, it issued 17 NOVs 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 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 EPA's success in detecting many violations through audits, it was in part 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.

4. Conclusions

One can draw several conclusions about the U.S. experience with phasing the lead out of gasoline. Not only was the program effective in meeting its environmental objectives, but it did so more quickly than it would have if it had not allowed permit banking. 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 marketable lead permit system was highly cost-effective, saving hundreds of millions of dollars relative to comparable uniform standards not allowing trading or banking. The banking program itself saved over $225 million, as it allowed for a more cost-effective allocation of technology investment within the refining industry. Also, estimates suggest that transaction costs brought about only a modest reduction in the efficiency of the market-based program of about 10 percent.

The market-based nature of the lead permit program also 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 suggests, 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.

While distributional issues are always a valid concern, 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. Moreover, environmental hot spots, which can be an issue with some localized pollutants, was not a significant concern in this case.

Unfortunately, the flexibility of the lead trading program 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 EPA's existing monitoring and enforcement costs. 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. 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.

Figure 1. Share of Unleaded Gasoline in Total U.S. Production

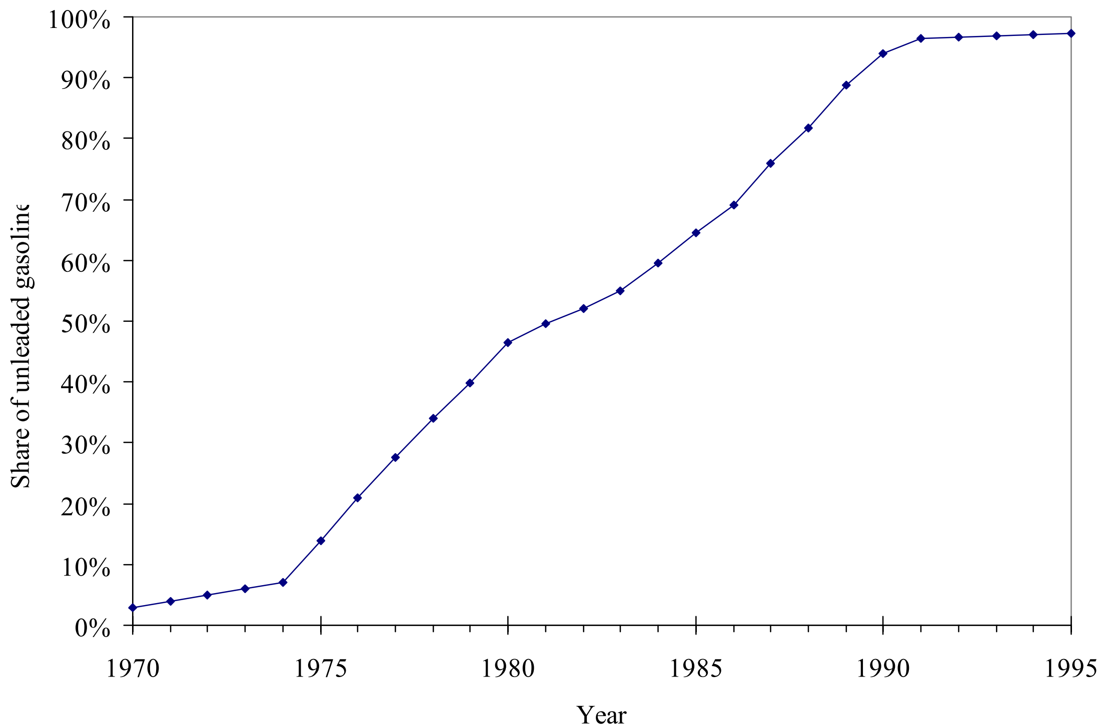

Figure 2. Lead Content in Leaded Gasoline (U.S. average)

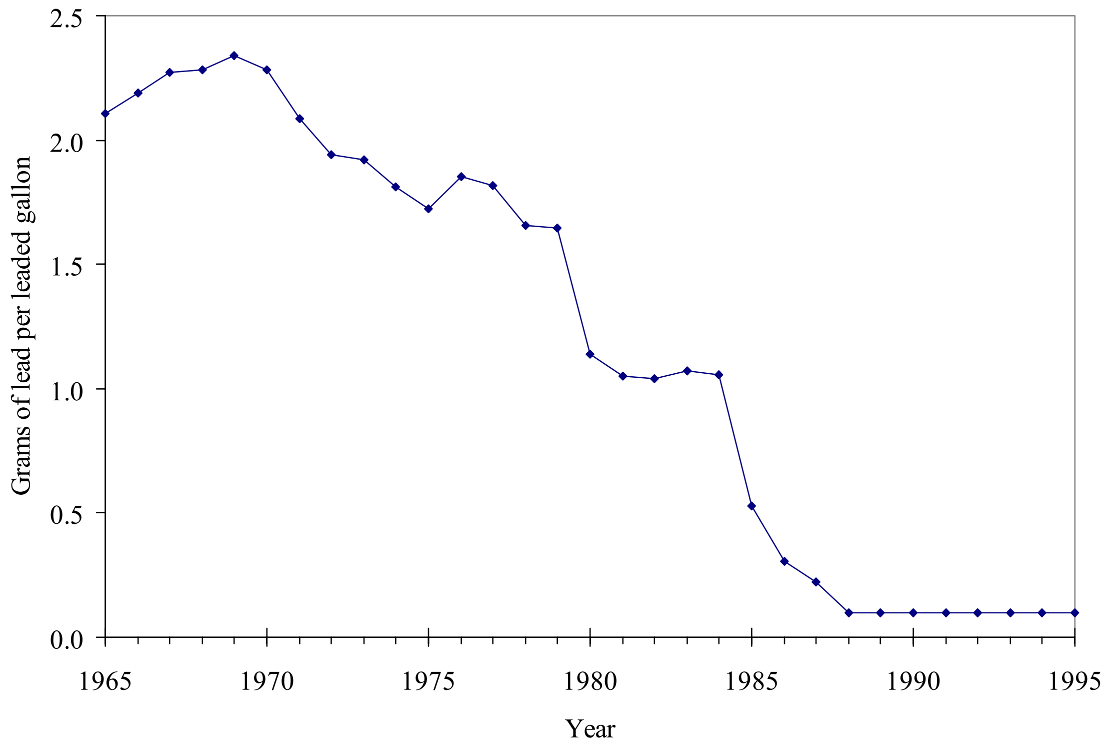

Table 1. Federal Standards for Lead Phasedown

Deadline	*Standard*	*Exceptions*
July 4, 1974	Gasoline retailers must offer unleaded gasoline and design fuel nozzles so that cars with catalytic converters can accept only unleaded gasoline.	Small retailers that sell less than 200,000 gallons annually and have fewer than six retail outlets are exempt.
July 4, 1974	Car manufacturers must design tank filler inlets to accept only unleaded gasoline and must apply "Unleaded Gasoline Only" labels.	The standard applies only to cars with catalytic converters, which became mandatory for model year 1975.
October 1, 1979	Refineries must not produce gasoline averaging more than 0.5 gpg per quarter, pooled (leaded and unleaded).	The standard is relaxed to 0.8 gpg until October 1, 1980, if a refinery increases unleaded gasoline production by 6% over prior-year quarter. Small refineries are subject to a less stringent standard. See Table 2.
November 1, 1982	Refineries must meet a leaded gas standard of 1.1. Interrefinery averaging of lead rights is permitted among large refineries and among small refineries, but not between refineries of different sizes.	Very small refineries are subject to a less stringent pooled standard. See Table 2.
July 1, 1983	Very small refineries are also subject to a standard of 1.1 (leaded). Averaging is permitted among all refineries.	—
January 1, 1985	During 1985 only, refineries are permitted to "bank" excess lead rights for use in a subsequent quarter.	—
July 1, 1985	The standard is reduced to 0.5 (leaded).	—
January 1, 1986	The standard is reduced to 0.1 (leaded).	—
January 1, 1988	Interrefinery averaging and withdrawal of banked lead usage rights are no longer permitted. Each refinery must comply with the 0.1 standard.	—
January 1, 1996	Lead additives in motor vehicle gasoline are prohibited.	—

Source: United States Code of Federal Regulations, 1996.
Note: gpg = grams of lead per gallon.

Table 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: United States Code of Federal Regulations, 1996.

Note: gpg = grams of lead per gallon; bpd = barrels per day.

Table 3. Physical Measures of Estimated Benefits of Final Lead Phasedown Rule

Estimated Effects	Year			
	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
NOx	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 4. Estimated Monetized Costs and Benefits of Final Lead Phasedown Rule

(in millions $1983)

Estimated Effects	**Year**			
	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.

References

Hahn, Robert W., and Gordon L. Hester. 1989. Marketable Permits: Lessons for Theory and Practice. *Ecology Law Quarterly* 16: 380–391.

Helfand, Gloria E. 1991. Standards versus Standards: The Effects of Different Pollution Restrictions. *American Economic Review* 81(3): 622–634.

Holley, John, and Phyllis Anderson. 1989. Lead Phasedown—Managing Compliance. Draft Internal Report, Appendix A. Field Operations and Support Division, Office of Mobile Sources, U.S. EPA

Kerr, Suzi, and David Maré. 1997. Transaction Costs and Tradable Permit Markets: The United States Lead Phasedown. College Park: University of Maryland.

Kerr, Suzi, and Richard G. Newell. 2003. Policy-Induced Technology Adoption: Evidence from the U.S. Lead Phasedown. *Journal of Industrial Economics* 51(3): 317–343.

Malueg, D. A. 1989. Emission Credit Trading and the Incentive to Adopt New Pollution Abatement Technology. *Journal of Environmental Economics and Management* 16(1): 52–57.

Nichols, Albert L. 1997. Lead in Gasoline. In *Economic Analyses at EPA: Assessing Regulatory Impact,* edited by Richard D. Morgenstern. Washington, DC: Resources for the Future, pp. 49–86.

U.S. EIA (Energy Information Administration). 1990. *The U.S. Petroleum Refining Industry in the 1980s.* DOE/EIA-0536. Washington, DC: EIA.

U.S. EPA (Environmental Protection Agency). 1985a. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis.* EPA-230-05-85-006. February. Washington, DC: EPA Office of Policy Analysis.

U.S. EPA. 1985b. *Supplementary Preliminary Regulatory Impact Analysis of a Ban on Lead in Gasoline.* February. Washington, DC: EPA Office of Policy, Planning and Evaluation.